Royal School
of
Bridges and Roads

1842 – 1843

Notes taken by students during the course on port construction

Of Slipways.

A slipway is an inclined plane on which ships are built. As this construction must serve for the launch of this same ship, the aim is to give it the gradient at which the vessel, sufficiently greased, would begin to slide. This gradient is usually $\frac{1}{20}$ for steamships, $\frac{1}{12}$ for vessels of larger tonnage, $\frac{1}{10}$ for those of medium tonnage, and $\frac{1}{8}$ for the smallest ones.

To construct a slipway on rocky ground, the ground is first leveled off, following a gradient varying from $\frac{1}{12}$ to $\frac{1}{10}$. Then a series of blocks or keel blocks are set up, whose heights are such that the ship's keel takes the appropriate inclination by resting on them (fig. 1). When the ground cannot be leveled, a grillage is built, made of pieces parallel to the shore, on which is laid a floor made of pieces parallel to the ship's axis, and it is on this floor that the keel blocks are placed. Finally, when the ground is very poor, this construction is built on piles, as is done in the muddy ground of Rochefort.

When a ship remains on the building ways for a long time, and this is considered a great advantage, the wood that has some defects rots, while sound wood does not deteriorate. It is no longer suitable to use wooden keel blocks; after 7 to 8 years these pieces would be rotten, the ship would settle unevenly, and this would result in drawbacks for the ship itself and difficulties for the launch. The entire slipway is then built in masonry, but if the ship rested immediately on its keel, since it is very flat towards the center, it would be impossible to get underneath; it is necessary to always leave two keel blocks 0.45 m high, raised enough to be able to nail the planking.

Launching on a cradle or berth. - If one now wanted to make the ship slide on its keel, it would be almost impossible for it not to tilt to one side or the other. The sliding plane must therefore be given a wider base. A cradle is then built, extending 2.50 m on each side of the keel axis; a kind of platform of close-fitting planks 0.10 m thick is laid; on these planks, a series of longitudinal pieces called keel blocks (*anguilles*) are placed. — Vertically on these keel blocks rise uprights (*colombiers*) which carry the bilge ways (ventrières); these are pieces that follow the inclination of the ship's side and support it directly. Besides the cradle, the ship is supported by large props (*épontilles*). — (fig. 2).

As the ship tends to spread the sides of the cradle, the rows of keel blocks are joined by iron tie rods. The two bilge ways were formerly joined by cables called *roustures* which passed under the keel. It was by means of these cables that the ship was lifted off the keel blocks at the time of launch. They were tightened strongly and wetted together. They would shorten and lift the ship. As these cables were always lost, costing 30,000 to 40,000 francs, they were abandoned. The cradle is secured with struts, and two superimposed rows of keel blocks are used. To lift the ship, wedges are driven simultaneously along the entire length of the ship between the two rows of keel blocks; the cradle rises as a single piece with the ship. The props are knocked away, and the cable attaching the end of the keel block row to a bollard or fixed post is cut (fig. 2).

Large ships are launched alone with a cradle. Once in the water, the cradle turns and floats. For a vessel of low tonnage, a corvette for example, it is made to slide on its keel to prevent it from tilting to the right or left. Two longitudinal pieces, called *fourrures* (packing pieces), are fixed under the flattest part, very low above the ground, which take the weight immediately if the ship leans to one side or the other. For finer ships, instead of using packing pieces, struts (*béquilles*) are nailed, tightened with wedges, which, joined at their lower end by a small packing piece, can bear on longitudinal bilge ways (*coëttes*). (fig. 3)

As ships are almost always launched into rivers or narrow basins, if the vessel were left to its own speed, it would crash into the opposite bank. Its speed is constantly slowed by means of a strong cable, 0.20 m thick, wrapped around several times, the turns being tied together in pairs with old pieces of cable, so that the main cable tightens. It must successively break all the knots, and this effort is enough to sufficiently retard the vessel. A three-decker, for which 15 or 16 knots are always used, never breaks more than 10 or 12.

If it happened that the slipway ended abruptly at the quay, as the stern of the ship, which enters the water first, is very thin, it does not displace a sufficient volume of water to be supported and tends to separate from the ship; it is then said that it would hog.

Suppose now the stern is sufficiently immersed and supported by the liquid, while the bow is not yet. There will be another effect; the stern lifting, the ship will tend to open up in the middle and the keel would sag. This latter circumstance would be very much feared for a steamship launched with its engine. The first of the drawbacks mentioned above is obviated by extending the slipway enough so that the ship does not cease to be supported before having displaced a sufficient volume of water. As for the second danger, the only way to mitigate it is to make the gradient as gentle as possible and to try to make the ship enter in horizontal layers.

The slipway extensions (*avant-cales*) are also used to haul a ship back onto the building ways; they are then called hauling-up slipways (*cales de hallage*). In this operation, one has to overcome the resistance due to the component of the weight plus friction. Now, assuming that the inclination of the slipway is such that friction just balances the component of the weight,

one would ultimately have to overcome double the component of the weight. By using rollers, or a railway, friction is reduced, but in any case, in evaluating the force to be exerted, it is better to be over rather than under the truth.

For this operation, simple capstans were used, each manned by 60 men; ropes were then used, but due to their elasticity, the ship only moved in jerks. The same happened with an unsupported iron chain forming a catenary; the use of capstans with whelps, onto which the chain links successively engage, is preferable. The chains used are made of iron 0.045 m in diameter. They can support 30 tons without breaking. As a tackle cannot be formed with these chains, a geared capstan is used; the cast iron shaft carrying the whelps also carries a cast iron wheel, 1.00 m in diameter, with teeth 0.15 to 0.20 m high and 0.05 m thick at the end; this wheel is driven by a pinion with 6 teeth, made of wrought iron or bronze. The ordinary capstan bars are applied directly to this pinion; 48 men, walking at a speed of 0.50 m/s, exert an effort of 30 tons. It is preferable to use a steam engine; this first ensures regularity of movement and, by making the winches horizontal, allows the chains to be placed more easily in the wells intended to receive them.

Construction of Slipway Extensions. In the Ocean, where the tidal phenomenon occurs, slipway extensions are built like slipways, working only at low tide.

In the Mediterranean, where the level differences caused solely by the varying wind direction are scarcely 0.60 to 0.80 m, the method used for other hydraulic constructions must be employed for slipway extensions. Old slipway extensions were entirely built of wood. Two rows of piles, spaced 8.00 m apart in the direction of the extension, were first driven, the piles being 1.00 m center to center. A floor parallel to the surface of the extension to be built was laid, and all the piles were cut off so that their heads lay in the plane of the extension. A very simple oscillating saw is used for this. To obtain a fixed axis, the uprights of the pile driver used to drive the piles are used; around this fixed axis, a rod attached to the crosspiece of an ordinary saw is oscillated; the saw is oscillated by means of two ropes attached to the two ends of the blade (fig. 4). With a radius of 15.00 m, this saw, costing only 60 francs, gives results that could not be expected from a circular saw, which, fixed at a single point, is easily displaced.

The interval between the piles is filled with simple rubble stone. During these operations, a grillage or double floor is prepared in a shore workshop, formed of close-fitting pieces 0.20 to 0.25 m thick placed in both directions; care is taken to arrange the workshop or build this grillage so that water can be let in and it can float; it is thus brought underneath the place it is to occupy. — Care is taken to obtain an exact plan of the pile heads in order to prepare in advance, with an auger, the holes intended for the wooden dowels. Once the floor is placed above the piles, it is settled by carefully guiding it, and with a pile driver and a small monkey, barbed dowels are driven in to fix it to the piles, care being taken that the heads of these dowels do not protrude.

To survey the position of the piles, an instrument is used consisting of a tin tube ending in three branches. From the top of the staging, it can be placed so that these three branches embrace the head of a pile; the tube is removed, thus obtaining for each pile a rod emerging from the water; the plan can then be surveyed with ease (fig. 5).

A slipway extension built thus in fir wood costs 300 to 400 francs per linear meter, but it has the great disadvantage of lasting only a short time; after 2 or 3 years it is completely riddled by *shipworms*. These worms do not attack buried parts; they destroy especially the parts that are alternately exposed to air and water. The Dutch have successfully used *mailletage* (studding). This operation consists of driving a large number of very thin, large-headed nails into the pile so as to completely cover its surface, but it has the drawback of being expensive and greatly increasing the weight of these constructions. A thin leather nailed onto the pile with small wire nails works very well; finally, Pouilly cement was used at Lorient. The pile was covered with nails that were not driven all the way in, then surrounded by a cement sheath 0.03 m thick, which perfectly protected the pile. — An Englishman recently proposed the use of a marine glue, very suitable, he says, for these purposes, which would also have the property of making detached portions of wood adhere, so that pieces of any desired cross-section and length could be formed at will.

Despite this, there is always an advantage in building a slipway extension in concrete; it costs about 1000 francs per linear meter but can last indefinitely.

Some slipway extensions were built with large cofferdams, which the use of concrete has made disappear. Generally, the ground is not poor enough to require piling everywhere and pouring concrete between the piles. It is only at Rochefort that this precaution had to be taken. — Sometimes also, it suffices to distribute the pressure over a larger area by means of a layer of sand, given a footing equal to the height of the masonry to be built. Most often, it is enough to dredge the soft parts.

After dredging, either with spoon dredgers or with bucket dredgers, two rows of piles are driven, spaced at most 3.00 m center to center, either to the right and left and 4.00 m from the axis of the ramp. As it would be difficult to erect staging on these two rows of piles spaced 8.00 m apart, two other rows are driven 3.00 or 2.50 m outside each of these ramps. Each pair is then joined by means of double waling pieces (*moise*) on which a tight floor is laid with wood screws.

As these piles have a considerable height above ground, it is necessary to brace them when they project far above water; a strut is placed between the piles.

In the opposite case, a frame with a St. Andrew's cross is prepared in advance, driven between the piles, and secured with wedges.

Besides this, the two longitudinal stagings are connected by a few 8.00 m long crosspieces intended to increase rigidity. — (fig. 6)

A coarse concrete is then poured between the piles; to save it, a few large blocks are thrown in, taking care that they do not touch each other. When the level is 0.20 or 0.25 m below the desired plane, a fine concrete is poured, using only rolled pebbles, usually quartz, at most 0.01 m in size, and passed between two screens, one fine and one coarse, to separate dust and larger stones.

These concrete pours were done with large hoppers carried on a frame sliding on the stagings. These hoppers were 0.40 to 0.45 m wide at the top and 0.25 m at the bottom. They easily clogged. An attempt was made to replace them with conical hoppers, with the large opening at the bottom (fig. 7). It happened that the truncated mass of concrete, separating from the hopper as a single piece, no longer filled it in the wider section, and water rushed in with extraordinary violence, washing away the concrete. The cylindrical or prismatic form was therefore adopted. But it is clear that the large volume of these hoppers was another serious drawback; indeed, they were 8.00 m wide, 7.00 m deep, and 0.20 m thick, so 17 to 18 cubic meters were needed to fill them. Now, before being able to slide it continuously on the two inclined planes, it had to be partially filled, and the time taken for this operation was never short enough to prevent the concrete at the bottom from starting to set. To prevent the hopper walls from deforming, they were connected by thin partitions 0.03 to 0.04 m thick, which did not exist at the bottom so as not to divide the concrete.

The large hopper was replaced by two adjacent hoppers carried by a single frame. This frame slides transversely on the main frame, which is moved on the two ramps. These two movements are done by means of winches (*vireveaux*). Two hoppers are used instead of one because the guys securing them would prevent them from approaching the edges of the slipway extension. (fig. 8)

When pieces 0.50 m thick cannot be obtained for the main frame, they must be reinforced. — These reinforcements essentially consist of cast iron pieces that support the beams from underneath (fig. 9).

Old slipway extensions were covered with dimension stone, usually limestone; they soon became pitted and covered with shells which screeched during launch. This drawback was remedied by using a floor formed of planks perpendicular to the direction of the extension, onto which longitudinal planks are nailed, aligned with those on which the keel blocks rest. Some time before launch, this decking is lifted, either because it is movable by means of hinges, or simply by using the flexibility of the planks; it is cleaned, greased, and weighted down with a few pig iron blocks.

Covering of Slipways. A ship on uncovered slipways exposed to the weather would be completely rotten after twelve years; when slipways were not covered, naval construction engineers used tarpaulins placed over the ship. A cover was later built with planks nailed onto the ship itself.

Covered slipways were built in wood at Rochefort. Figure 10 indicates the main wooden pieces used. The roof is covered with small scaly fired tiles, pierced with a hole, and nailed onto the battens running from one truss to another. Some slipways have been covered with wooden shingles, but these must be coated and painted. Zinc or galvanized sheet iron is now used. These sheets have very marked advantages over zinc: firstly, the price of the latter metal has greatly increased; secondly, it burns very easily, and in case of fire, a covering disappears immediately. The processes given by Mr. de Ruolz for the application of metals onto each other have further facilitated the use of galvanized sheet iron. These sheet metal coverings are very light and must be attached with great care, otherwise they would be blown away by the wind.

Grouped slipways are now preferred to isolated ones. They offer the advantage that a series of supports serves for two slipways. At Toulon, 15 covered slipways are being built, arranged in three groups of five each. The exterior parts must be made of masonry, as in wood they would rot too quickly. The English have built contiguous covered slipways where the entire yard is sheltered from the rain (fig. 11).

Of Ports in General.

Maritime works have as their object the construction of ports, their maintenance, and the defense of coasts against the sea, especially in regions where the tidal phenomenon occurs.

Ports designate a locality where ships can be built and repaired, where they are sheltered from the agitations of the sea and from enemy attacks. — A distinction is made between military ports and commercial ports; the aim of these two types of ports is essentially different, consequently so are their location conditions. For a military port, a cape, a headland is needed, from which the enemy can be seen and pursued in almost all directions, for in naval warfare, success often depends on the possibility of striking first. For a commercial port, on the contrary, a location is needed such that upon leaving it, one is as quickly as possible in the interior of the country, and moreover, communications with the country must be easy; a deep cove perfectly satisfies the first of these conditions; if, in addition, there is the mouth of a large river in this cove, the essential conditions of a commercial port are combined. Thus, goods leaving Brest would have been obliged to travel a long and costly overland route, whereas from Le Havre, Rouen, Nantes, they immediately reach large population centers. Some other ports, called ports of refuge, are intended almost solely to offer shelter to vessels either after a storm or after a naval battle.

For a military or commercial port to be complete, it must contain all the establishments necessary for the construction and repair of ships; it must present exits that are easy to navigate in all weathers; these exits must always have sufficient water depth and be sheltered from siltation; finally, in a port, ships must have nothing to fear from the movements of the sea or from enemy surprises.

The establishments necessary for ship construction can be set up in almost any locality, but calm, water depth, and ease of entering and exiting in all winds are very often conditions difficult to reconcile. Before examining these conditions, one must try to understand the various phenomena presented by the movements of the sea.

Of Waves. The equilibrium of the sea's waters almost never exists. It is disturbed by various causes, many of which are unknown to us. Among those we can appreciate are evaporation and the great tributaries coming from inland, the alternating attractions of the sun and moon, and the winds.

Winds modify the surface of the water. Their first effect is to produce a raising of the waters in the direction opposite to their action; thus, in the Mediterranean, when the wind comes from Africa, the level on the French coast rises by 0.50 to 0.60 m. The sea, thus inclined, does not remain smooth; undulations or waves form on the portion above the former level of the still waters. The lower part of the wave is called the trough; it is these waves that need to be studied, for it is from their action that coasts must be defended.

The translational movement that waves seem to present is only apparent. A floating body of density almost equal to that of water does not change place appreciably. Several hypotheses have been presented to explain this phenomenon. Brémontier supposed that the molecules composing a wave rise and fall vertically and continuously siphon one another; consequently, a floating body rises and falls vertically, if the movement does not occur exactly vertically. This displacement would be due to the action of gravity on the part of the body outside the liquid, which would make it descend as on an inclined plane, and the amplitude of the vertical oscillation of the floating body would be the same as that of the wave.

Orbital motion of waves. A floating body subjected to the action of waves does not move as indicated by this theory of Mr. Brémontier. If, from the shore, one attentively observes a floating ball in a place where waves succeed each other very regularly, one sees that in the crest part, it moves towards the land as if its motion were due to the wind, and in the trough towards the open sea. From these two movements, since the body has no translational movement, the orbital movement of the liquid molecules is evidently arrived at.

Mr. Colonel Emy rejected Brémontier's theory. First, the cause assigned for the descent of the floating body along the wave cannot be admitted, and even for this cause it should rise, for it is known that a light body, wetted by water, immersed in a vessel containing as much liquid as possible placed near the edge, rises to the top. Next, water is incompressible. It must therefore be admitted that this vertical oscillatory movement is transmitted without alteration to the bottom of the sea.

It is difficult to think that the slightest wind is enough to set in motion such a considerable mass of water. It is much more probable that the agitation of the waters is only felt at a shallow depth, and that there exists a plane that is undisturbed. Imagine a plane parallel to the direction of the wind, and let *c d* be the trace of the undisturbed plane on this plane, *a b*

the level of the still water. Divide the total volume into equal prismatic volumes by planes perpendicular to the plane of the figure. Suppose that waves form and have reached a uniform length, and consider what must happen between the crests of two consecutive troughs. There can only be alteration in the form, not in the volume of the fluid mass, and at the wave crest. For example, the slice *NN′ x y* (fig. 12) will become *NN′ u u′*, but as there must be continuity, the neighboring slices will incline on *NN′ u u′*; now the wave crest, before being on *NN′ u u′*, was on the slices to the left, and will soon be on the slices to the right; therefore, the slice with base *NN′* began by inclining to the left, taking the forms of the slices now to its right, then it will incline to the other side, taking the forms of the slices which are to its left; therefore, if one wanted to have the successive positions of *NN′*, the forms of all the slices 9, 8, 7, ... 3, 2, 1 and their succession would indicate the direction of the molecule's path. It can thus be seen that each molecule has an orbital movement, and that it goes in the direction of the wind in the crest, and in the opposite direction in the trough.

Newton supposed the oscillatory movement of fluid molecules to be vertical, but he recognized that this hypothesis was made only with the aim of simplifying the calculation and that really it was necessary to admit that the movement of these molecules was *per circulum*.

Modifications made to waves by an obstacle. Be that as it may, whether the molecules of waves move vertically or not, the important thing is to study the effects of these waves and the means that can be employed to prevent their propagation.

When the wind begins to blow over the surface, the water ripples; weak, closely spaced furrows appear; as the wind rises, if the depth is sufficient, the wavelength increases, and the wind remaining constant, it reaches a uniform length.

When the wave encounters an obstacle, an inclined plane, its length decreases and its height increases; if the plane is very steep, the wave diminishes little by little and comes to nothing. The Dutch have based effective defensive works on this fact, using sand dunes sloped at $\frac{1}{20}$ and covered with straw wattling to prevent the sand from being carried away.

If the obstacle is vertical and not as high as the wave, the undulation decreases in length, increases in height, and overcomes the obstacle; but if the obstacle is indefinite in height, the undulation arrives full and complete and rises almost vertically. Along the obstacle, part of the molecules form an inclined plane on which all the others slide; there is a complete flow of the upper part of the wave. The height to which the water rises is greater the longer the wave has been; in any case, it is much greater than the height due to the velocity of the liquid.

The water thus raised to a considerable height along the obstacle falls back into the sea and thus produces a new wave called a *return wave*, *reflection wave*, or *undertow*. As water is an incompressible body, it is much more probable that the undertow is produced much more by the *fall* of a part of the wave already flowed back onto the arriving wave, than by a return, a reflection on a plane; the liquid is assimilated to an elastic fluid.

When the wave moves between two vertical planes and the bottom is horizontal, there is no appreciable alteration; the waves are parallel (fig. 13). But if the bottom rises, the wave bends (fig. 14) and tends to take the shape of the horizontal contours of the ground. The waves then become more and more narrowed towards the cape, while in the cove they lengthen greatly and arrive almost horizontally at the shore.

If waves arrive in a large basin through a narrow opening, as the volume of each can be regarded as constant (this cannot be demonstrated, but it seems evident that the force producing the oscillation of the liquid being constant, the volume of agitated liquid must be the same, neglecting the influence of coasts and all other friction), the width increasing greatly, the height consequently diminishes, so that by the sole means of a narrow channel, calm can be achieved in a large basin.

If, on the contrary, waves arrive in a re-entrant angle, the width diminishes and the height increases considerably, so much so that at the back, waves which at the entrance were only 1.00 m high reach 14 and 15.00 m.

Breakwaters. Between successive waves, there seems to be a complete adherence in the fluid, to such a point that if this adherence is destroyed by means of openwork structures, lattice jetties, almost all the agitation disappears behind these piers. It has thus been possible to have in a channel leading to a port basin only a very small part of the agitation which, without these arrangements, could have been considerable (fig. 15).

The agitation of waves is not the only thing to be guarded against in a port; considerable siltation occurs in certain places in the sea; it is therefore essential to study the causes of their formation and the means of preventing them if possible. This phenomenon of siltation, linked to that of wave movement, also depends on the existence of certain currents that prevail in the seas and whose causes are often unknown.

Of Currents. Currents are of two kinds, general or limited. At the mouths of rivers and streams, currents are produced due to the arrival of their waters in the sea, but besides this, there exist great general currents which, in the ocean, appear to depend on the tidal phenomenon. In the Mediterranean Sea, there exists a littoral current whose cause is not well known. It is not felt more than 3000 m from the coasts and manifests itself in coves. It flows from West to East. On the African coast, in the opposite direction; on the French coast, everywhere from left to right looking at the sea; its speed does not exceed 0.07 to 0.08 m/s in calm weather; it reaches 0.50 m/s with certain winds; by itself, it would be incapable of transporting pebbles or even sand.

Consider a current moving between two vertical planes on a very gently sloping bottom. If the section is suddenly widened, the movement no longer occurs over the whole length by parallel filaments; the current leaving the narrow channel carries with it the liquid molecules that were at rest in the re-entrants, and two eddies form there. The position of these eddies is important to consider in each case, because if the current transports gravel, it always deposits

it in the places where these eddies occur. If, instead of widening, the channel narrows suddenly, the liquid level rises and there is a backwater slope; the liquid filaments bend to enter the narrow channel, and there will be two eddies in the corners; moreover, due to the very direction of these filaments, we return to the case of section widening and eddies form at the point of fluid contraction.

The phenomenon of the backwater slope observed by Mr. Bidone in artificial canals occurs on a very large scale in the case of the tide coming from the open sea when entering a narrow basin.

Suppose a current is suddenly stopped by a barrage of indefinite height. A swell immediately occurs in front of the barrage. This swell propagates in the opposite direction to the current, and the liquid molecules remain in absolute rest immediately after this rise. If the obstacle is low enough for the current to pass over it, a swell first occurs as before, then the level abruptly lowers downstream and rises again; this is the phenomenon of the undertow.

Instead of a current and a solid obstacle, suppose two currents meet; if these two currents go in opposite directions, at the moment of meeting, both will rise, and if they are equal, the swell will travel over each of them from the meeting point as in the case of an indefinite obstacle, and the whole mass will come to rest as this swell occurs.

If one of the two currents is stronger than the other, there will be a rise on each side at their meeting, the swell will travel against the current, and the whole mass will move in the direction of the stronger current.

Suppose a current flowing along a coast and passing in front of a creek where the water level is lower; the current will not enter immediately into the creek; it will pass it and then return; an eddy will form at *a b* (fig. 16).

If a current, skirting a coast, is met by another current coming from inland, this second current will bend and there will be an eddy at *a b* (fig. 17).

If a current coming from inland arrives in a tranquil basin, two lateral eddies form (fig. 18).

Finally, if a current encounters an island, two lateral eddies will form and a siltation at the head of the island.

Of Tides. The tide is the periodic movement of ascent or descent of the sea's waters.

The rising movement which constitutes the rising tide is called the *flood*, *rising flood*. The falling movement which forms the falling tide is called *ebb*, *falling tide* (*Ebbe, jusant, reflux*). The sea rises and falls twice in approximately 25 hours. These movements of the sea are due to the relative positions of the heavenly bodies.

The level of high and low tides varies each day; the higher the sea rises at high tide, the lower it falls at the following low tide, and it always takes about the same time, approximately 6 h 12'. It is at the times of *syzygy*, that is, full and new moons, that these movements are

greatest, and it is at the *quadratures* that they have the least amplitude. The tides of *syzygies* are called *spring tides*, and those of quadratures *neap tides*.

The spring and neap tides of different lunar months do not rise to the same height; the highest spring tides and the lowest neap tides occur around the equinoxes, and the opposite effect occurs at the solstices.

The total tide of a day is called half the sum of the heights of two consecutive high waters above the level of the intermediate low water. At Brest, the average resulting from a large number of observations is 3.21 m. This number is the unit of height for this port. The yearbook of the Bureau des Longitudes gives this unit for eight ports from Dieppe to Lorient.

In the open sea, high tide lags 36 hours behind the passage of the moon at the meridian. In ports, the diversity of coast shapes delays the time of high water even more, on the day of the new moon, but for each port this time is constant; it is called the *establishment of the port*; this time is given for each port in the longitude yearbook.

If the earth were a solid nucleus surrounded by water, there would be only one current everywhere, moving in the same direction; this current indeed occurs in large seas where there are no obstacles; also, in coves in the Mediterranean, the waters do not participate in these movements. For in the interval from one high tide to low tide, the cove would need time to fill or empty. If these remarks are applied to the Mediterranean Sea, for the effects of the tide to be felt there, an enormous volume of water would have to pass through the Strait of Gibraltar, and if one calculates this volume and the section of this strait, an impossible velocity is found. Also, in the Mediterranean, the level differences due to tides are only a few centimeters.

The general remarks made on any currents apply very well to tides; an example of this is what happens in the English Channel. The tide, which is only 6.8 m at Brest from low to high water, finds a re-entrant towards Granville and St Malo in the Channel, so in these ports it reaches 11.5 m and 10.5 m. At Cape La Hague, the Channel narrows considerably; there is a backwater slope, then a downward slope for the tide, and at Cherbourg it is only 5.6 m. At Le Havre, in a cove, it becomes 7.1 m again, then the Channel narrowing further, the sea swells towards Boulogne where it is 7.9 m, then it descends and there is a flow towards Calais, 6.30 m, and Dunkirk, 5.3 m.

Slack Water. Like all quantities that vary continuously, passing through a maximum and a minimum, the sea always remains high or low for a certain time. The time of high water is called slack water. The duration of slack water varies in different ports. At Granville and St Malo, it is very short. The opposite occurs at Le Havre where it lasts nearly two hours; this circumstance is an immense advantage for this port, because ships can easily enter or leave for a long period of time. This phenomenon is attributed to the general current which flows from S.W. to N.E., which splits at Cape Antifer to enter the Bay of the Seine and continue towards the Somme. The point of separation of the currents is necessarily higher than the levels reached by the two descending branches; the sea therefore only begins to fall at Le Havre

when it has become lower than the water at Cape Antifer, which will require a certain time. Moreover, during the ebb, there is a factor tending to raise the water level on the Le Havre side: the Seine, which flows towards Honfleur, produces a large eddy on the Le Havre side.

Tidal Curves. The tidal phenomenon is not that of the production of a single regular wave. If one imagines a horizontal line on which times are plotted, and on the ordinate the heights to which the water rises, a more or less undulating curve is found (fig. 19). This is a fact analogous to that of harmonic sounds; it is known that a vibrating string can subdivide into several parts which vibrate separately, at the same time as the large oscillations occur. Moreover, it has been noticed, by carefully studying tidal curves, that these secondary oscillations behave with the main oscillation in the same way as harmonic sounds with the fundamental sound.

Tide Wells. The tidal curves just mentioned are constructed in tide wells; there is still only one at Cherbourg. Water enters a well through a channel which should be made as long as possible to avoid errors due to liquid agitation. In the well, a float carries a rod with a tracing point. A sheet of paper is moved at a uniform rate, and thus the relative heights of the liquid are obtained at each instant. To avoid using too large a sheet, tracing points can be placed on the rod at different heights, so that one starts marking when the other leaves the paper. The entire curve can then be very easily reproduced.

Of Siltation.

The causes of siltation were long unknown. The first research on this subject was done in Italy, where cities like Venice saw their existence compromised by the silting up of their ports. Rivers flowing into the Mediterranean bring a considerable quantity of sand. Montanari observed that when a river flowed into the Adriatic, there was always a siltation to its right. Considering the path of the littoral current in the Adriatic, it is seen that the eddy is always to the right of river mouths, where siltation occurs. When instead of a river there is a lagoon, the siltation is always on the left.

The littoral current of the Mediterranean by itself would not set the sands in motion, but the agitation of the waves lifts the sand layer, and as it does not influence the current's movement, it follows that the current transports the sands always in the same direction. As soon as the agitation ceases, the sands settle, only to be set in motion again at the next agitation; but if the calm is no longer disturbed, the silting remains. Numerous facts attest to the truth of this.

Under Richelieu, a port was to be built at Cape Agde. There was a very deep cove; to create calm at the entrance, which was exposed to storm winds, a mole 800.00 m long was built whose construction lasted 17 years. But by that time, an immense siltation had also formed in

this calm area, and the shoreline started from the point of the dike. There were only 2 or 3 small channels through which the Saint-Martin lagoon filled and emptied.

At Sète, analogous circumstances occurred. There was a very deep cove where sands did not settle, but which was exposed to all the violence of the East and Southeast winds. In 1666, a dike was built to create calm. After 10 years, there were 800,000 m^3 of sand in the port, which had to be dredged. To prevent the port from being completely lost, considerable annual dredging was resorted to. The idea came to build a second jetty and to cover the port entrance with a breakwater to stop the sands. This resulted in siltation in the channel, so that in summary, wherever calm was created, there were sand deposits.

This question of siltation, fundamental for the study of maritime works, presents itself from other points of view. Siltation can come from sands brought by rivers or from the erosion of banks. It is useful to study the progress of this erosion. This phenomenon was examined on the coasts of Normandy by Mr. Lamblardie. Here are some passages from his fine memoir.

"The coast vainly opposes to the efforts of the agitated sea great cliffs 200 feet high. These cliffs, composed of beds of marl separated by layers of flint, are undercut at their foot by the shock of the waves; soon the whole upper part overhangs, breaks away, falls, and shatters due to the fall; the sea completes the division of this mass, and the waters become charged with marl they have diluted, to form deposits; the flint is rolled along the coast by the repeated shock of the waves, it wears away, its angular parts break off, it becomes rounded, finally acquires a spheroidal form and then takes the name of shingle. All that the flint loses of its primitive form in passing to that of shingle is converted by friction into small gravel and sand. To the continual efforts of the sea are joined other causes which contribute to the destruction of the cliffs: almost vertical fissures receive rainwater which filters through the upper strata. When these fissures are parallel to the face of the cliffs and the water they contain in winter is sufficiently exposed to the influences of the air to freeze, the dilation can only divide them: thus the destruction of the cliffs is an effect of nature against which art could only oppose a vain resistance."

"If the action of the waves is inclined to the coast, their effect is decomposed into two others, one perpendicular to the coast, the other parallel to it; the first effect tends to destroy the cliff, the second rolls the shingle along the coast and leads it into the ports and bays it finds in its path. Thus, all other things being equal, the more parallel the direction of the waves to the coast, the more considerable the path traveled by the shingle would be; but it is well understood that with the same wind force, that whose direction is parallel to the coast should not form the strongest waves, and consequently, waves parallel to the coast should not bring the most shingle. When the wind direction makes an angle of 45° with that of the coast, the shingle will have its greatest possible speed, relative to the greater or lesser force of the wind."

"The opinion of those who think that shingle comes from the open sea must be rejected, because shingle has never been found in the hollow of reefs nor in the pens built here and there along the shore, and if shingle came from the open sea, it would begin by filling them.

We have several times observed, *in calm weather*, that the tidal current gave no movement to the shingle along the coast."

Thus, the shingle advances along the coast, but two quite separate movements must be distinguished. If the wave arrives obliquely and there is great depth, it makes the shingle climb up in front of it, then it descends with it, the shingle following the line of greatest slope until the following wave takes it again and places it in the same circumstances. If there is not sufficient depth, the wave makes the shingle jump. It then participates in the current's movement and advances by leaps.

Let us return to the shingle of the Normandy coasts.

"All this shingle runs along the coast in two diametrically opposite directions. At Le Havre, looking at the sea, it comes from the right. At Tréport, at Dieppe, at St Valéry, at Fécamp, it comes from the left, and these two movements are only occasioned by the lie of the coast, which forms a salient angle between Le Havre and Fécamp, to the right and left of which the force of the waves is decomposed along the shore into opposite directions. This salient angle is Cape Antifer. The direction of the most violent and frequent winds from the N.W. part, which prevail in the Channel, divide it into two equal parts, so that the shingle is obliged to split there. One portion passes Le Havre and forms the Pointe du Hoc; the other portion passes Fécamp, St Valéry, Dieppe, Tréport and comes to augment the territory of Cayeux, forming the Pointe de Bourdel. The shingle obstructs in its course all the ports it meets in its path; the excess is rolled as far as the points just indicated."

Thus, shingle moves by the simultaneous effect of current and wave. In the Mediterranean, only the S.E. wind makes the shingle move; it goes in the direction of the littoral current between Agde and Marseille. The wave can make the shingle move in the opposite direction to the current. Sometimes, due to local circumstances, the movement of shingle always takes place in the same direction; thus, it always goes from Cape Antifer to Le Havre, even at ebb tide, because then the current of the Seine forms an immense eddy on the right.

Shingle has also been observed in the Gulf of Gascony; some extracts from a report by Mr. de Baudré will give an idea of their movement on these coasts.

"Off Bayonne, the currents from the open sea run from south-west to north-east; they run up to 4 or 5 knots (the knot represents 0.5 m per second). This direction depends on that of the wind *and does not change at ebb tide*; when regular northerly breezes have set in, the currents change direction and run from N.E. to S.W. Beyond Cape Ferret towards the Gironde, the prevailing winds are closer to north and the currents depending on them always run in the opposite direction to that occurring in the south of the Gulf. The very pronounced inclination towards the north of the Pointe de Grave at the extremity of the left bank of the Gironde would seem to be an indication of this. This reversal of the current, which would appear to occur in the passes of La Teste, could have given rise to the prominence of the Pointe d'Arcachon and the remarkable progress of the dunes in its vicinity. All the streams flowing into the sea on

this coast, from the Bidassoa to Cape Ferret, *without exception*, incline at their mouths towards the south."

"The waves come constantly from the West, they break on a coast that runs approximately from S.W. to N.E."

"Northern breezes are of short duration. The Bayonne bank forms in its development a great arc of a circle in front of the Adour mouth. It is attached to the shore and is always outlined to the view by the breaking of the waves which break there simultaneously. This line of breakers is linked to that which borders the coast, at the foot of which the wave always breaks with enough violence to maintain the shore on a slope whose base is only two or three times the height, and sometimes much less in the inner part."

"The sea, which only suffers gravel on the ridge of the bar, also cleans the shore against which it beats of all fine sand; only gravelly sand mixed with very small rounded gravel is found there."

"The interior of the beach, however, is only composed of very fine sand. The whole bottom of the Adour basin up to Bayonne is also fine sand when it is not muddy or rocky."

"The gravel of the bar comes from the south. From Cordouan tower to La Teste, the seabed is almost constantly composed of sand without any admixture of gravel; from La Teste to the Adour mouth, the latter becomes more frequent without ever appearing on the coast at less than eighty to a hundred feet of depth. From the Adour to the Bidassoa, there exists an immense plateau of underwater rocks. Gravel is found there in a large number of points, without however being encountered on the coast."

"In 1783, the head of the south jetty was 1169 meters from the bar; today, this jetty is considerably closer to it, only about 445 m distant."

"Great storms, extraordinary floods, the direction and intensity of prevailing winds produce great disturbances; the bar no longer appears to be anything more than isolated banks scattered in all directions, and the river channels multiply there; the shoreline advances seaward or recedes, either on one bank or the other."

"The bar can be considered as the underwater continuation of the shore, which the river's action depresses or pushes back in front of it like a fan. If the action of the wave accidentally became superior to the movement of the river's waters, the shore would immediately take back, in place of the bar, the shape it assumes on both sides of this bar. This is what happens at St Jean de Luz in the interval of a neap tide, when all favorable circumstances concur to this effect; then the mass of alluvium of the bar is thrown successively by the impetuosity of the wave between the high jetties, filling the interval sometimes over more than 80.00 m in length up to their coping. It is only when the sea is calm and allows approach to this enormous barrier that, with the aid of kinds of ploughs, a small trench is opened to give a start of outflow to the waters of the basin. The scouring of these waters, which have swelled during the

time of retention, soon completes the work, and the bar re-establishes itself in its usual position."

Mr. Colonel Emy supposes that shingle comes from the open sea, and he seeks proof of this opinion in circumstances he believes he has recognized, where the apparent translational movement of waves would be transformed into real movement. He supposes a depth such that the oscillatory movement can take place freely, and that suddenly the bottom rises abruptly and the oscillatory movement is hindered. Mr. Emy then supposes that the horizontal layers above this bottom continue to move as before, but that the fluid masses between the ground and the last wave, pressed by this wave against the ground, flee before it with a speed equal to the apparent speed of the flood. An underwater current, which Mr. Emy calls *the undertow*, is thus formed and rolls the shingle to the shore. Now, if such a mass of liquid came to pour onto the shore, there should evidently be formed at the surface an eddy, a terrible counter-current, and nothing proves the existence of this current. Moreover, if a mass of density slightly greater than that of the liquid were thrown into the sea, it would be almost instantly thrown back to the shore; but nothing like that happens. Finally, if undertows existed, why would no shingle be found in the pens situated a short distance from the coasts? If, finally, sands came from the open sea and were brought by undertows, how to explain that over 100 leagues of coast there would constantly be siltation, and that this siltation would abruptly cease over an almost equal length?

Mr. Mercadier studied the facts resulting from the coexistence of a tributary and a littoral current; he observed, as Montanari had done before him, that when the littoral current passed in front of a lagoon, the alluvium was to the left of the lagoon; when it passed in front of a river, the alluvium was to the right. We have seen that a current passing in front of a creek did not enter perpendicularly into the void to be filled, but turned and entered obliquely. An alluvium then indeed forms to the left of the lagoon; then this lagoon emptying, the waters tend to flow along the line of greatest slope; they dig a channel in the formed alluvium, and an island then forms at the mouth of the creek. If instead of a lagoon there is a river bringing sand, if there is no littoral current, two islands joined by a bar form. If there is a littoral current, there is an eddy and siltation to the right. This siltation increasing continually, if the tidal phenomenon occurs, the river then flowing into the sea cuts through the siltation, and it seems that there is siltation to the left. Mr. Mercadier concluded that where there was an eddy, sands settled, that consequently by crossing them with a current, these deposits would be prevented.

Now, a current cannot prevent alluvium; indeed, the Giens peninsula near Toulon was certainly an island formerly, and there was a current between it and the coast; however, the sands rolled by the Gapeau all settled to the right of this river, under the shelter formed by this island, and joined it to the shore. The current then skirted the Giens island and, passing it, formed a large eddy and a new siltation behind the Giens island. These two siltations today enclose a large lagoon which cannot fail to be filled in later. A similar thing happened at the

entrance to the Toulon roadstead, and what is called *les Sablettes* is evidently a siltation closed in the shelter of the small island, although there was a current between it and the shore.

The existence of these siltations between the shore and islets could also answer Mr. Emy's hypothesis, for if they came from the open sea, they would be on the outside and not constantly on the inner shore. How then to explain the movement of sands around the islands, a movement which would necessarily have to be admitted? And moreover, the nature of these siltations is known: the coast from Cape Cepe to Les Sablettes is sandstone, and it is found nowhere else; now all the sand at Les Sablettes is sandstone. It is therefore very rational to attribute this siltation to the destruction of the coast upstream (relative to the current) and to the transport of the product of this destruction along the coast. The same is true of the 2 siltations behind the Giens island; they come from the Gapeau river. By carefully examining the nature of the sands taken from the river and from the siltations, perfect identity is found.

It can therefore be said that when there is agitation, the current carries the sands, but as soon as agitation ceases, the sands settle.

Mr. de Fazis, Inspector General of Maritime Works of the Kingdom of Naples, proposed the use of lattice moles, like some ancient moles built by the Romans, to combat siltation. A translation of his memoir can be read in the Annales. But lattice moles either produce calm in a port or they do not. If they do not produce calm, they are useless; if they do, sands must inevitably stop.

In summary, one must renounce preventing sands from settling if calm is desired, and for the location of a port, localities where no sand passes must be chosen, or one must resign oneself to dredging continually.

Generally, capes present suitable localities. There is no alluvium at Cape Antifer, while there is on both sides. At Cherbourg, at the end of a granite peninsula, there is no sand; the same is true for Algiers. Between Toulon and Marseille, there are no rivers bringing much sand; from the Rhône to Collioure, there is little or no siltation; on the contrary, everywhere there is sand, the presence of mud is a good indication of the absence of sand. If one were forced to build a port in a roadstead subject to silting, the port should be placed downwind, so that siltation reaches it as late as possible. Thus, the port of Antibes was well laid out.

What is especially important is that siltation does not settle in the channel, as happens at Sète; a place must then be created where the sand will settle, i.e., a sand trap must be formed. It will, it is true, have to be dredged continually, but this can be done at will; one can wait until the sand is 1.00 m below water level, which will always be more convenient than dredging in a channel with 5 to 6 m of water; and navigation will not be hindered during these dredgings. At Sète, the Fontignan jetty would need to be breached on the land side and inclined towards the shore. The sand trap would work very well in the shelter of what remained of this jetty and the breakwater, and the channel would always have the necessary depth.

On the ocean, gravel can be somewhat removed by scourings; but as a scouring never digs more than 2.00 m below water, this means cannot be relied upon to maintain sufficient depth in a place where there would be considerable siltation and where the tidal phenomenon does not occur, because in the ocean, if to the 1.50 or 2.00 m of depth given by scourings we add 5.00 m of tide, we will arrive at sufficient depth to establish a port.

Of Roadsteads.

It is essential that in a port, vessels be sheltered from the agitation of waves, but also that at a certain distance from the port, vessels still find a certain calm and a sure defense against the enemy. This space in front of the port where vessels can anchor under sail is called a roadstead. If ships were gathered in a narrow locality and moored to a quay, at the slightest agitation of the waves they would smash against each other or against the quay. They must be perfectly isolated. In a roadstead, ships are held by an anchor. It is known what an anchor is; the anchor carries perpendicularly to the plane passing through the anchor flukes a piece of wood called the stock (*Jas*). When the anchor touches the bottom, two cases can occur: either it presents itself well, the fluke bites, and that is all; if on the contrary the stock rests by one of its ends on the bottom, it cannot remain in this position. It is dragged by the rope attached to its middle, which trails on the bottom; the stock, in tilting, forces the anchor fluke to enter the ground.

Completely closed roadsteads are rare; some open to all winds from the open sea are called *open roadsteads* (*rades foraines*).

On rocky ground, the anchor does not hold. Wet sandy ground does not offer good holding; however, it is possible to anchor there if necessary. The best bottom is compact mud or sand mixed with mud.

When wishing to establish a roadstead, it is essential to know the quantity and tonnage of the vessels it must contain. For a military port, having a large roadstead is essential, as a great number of vessels must be ready together to get under way. The area necessary for a vessel at anchor depends on the water depth. For good holding, the cable length should be 5 times the depth. 3 times could be sufficient if necessary. To this length must be added that of the vessel, about 70.00 m, to obtain the radius of the circle that the ship's extremity can describe around the anchor. In summary, about 10 hectares are needed for one ship. This space can be reduced by having the vessel moor on two anchors. This operation is called *affourcher*. A first anchor is dropped, then a launch is sent to carry a second anchor until its axis bisects the angle of the two anchor cables. It can then be seen that the vessel, held sometimes by one cable, sometimes by the other, cannot leave a certain space smaller than the previous one. The area required for a vessel is then reduced to 5 or 6 hectares.

Apart from the question of alluvium, it is easier to create a port in the Mediterranean than on the ocean. For on the ocean, between high water and low water, there is always an area that must be crossed to reach the open sea. A channel is enclosed between two jetties, close enough together for the wave agitation to spread and die out.

The particular study of the main French ports will highlight the advantages to be sought in a roadstead.

Brest. A remarkable natural roadstead, presenting a combination of circumstances that make Brest one of the best ports. In a cove, sheltered from the agitations of the ocean, by a passage only 1600 m wide, flows a small river, *le Penfeld*, which at low water has 8.00 to 10.00 m of water; it is on this river that the town of Brest is established. The roadstead can contain 150 ships of the line and an indefinite number of small vessels. The only drawback it presents is perhaps its extent, for it has the agitations of a true sea; thus, the port receives a little agitation when the wind comes from the south. Brest has long been a complete port; the establishments for steam engines now being built there will enable it to meet the demands created by this new mode of navigation.

Cherbourg. The port of Cherbourg, on the contrary, is a port entirely created by man. Its position on a very prominent cape is well known, such that no ship can enter the Channel without rounding it. We have seen that there is no silting. In 1778, the importance of this position was recognized, but a roadstead had to be created there. Studies were incomplete and poorly done. A dike starting 600 m from the coast was planned; it would have been defended by the fire of two forts established on Isle Pelée and at Pointe du Homet. But firstly, soundings had not been done or had been poorly done. Isle Pelée extends with underwater rocks to a great distance, and not 4 ships would have fit in the roadstead. Secondly, it would not have been possible to leave the roadstead at will, for a ship cannot sail before having at least six points of wind, i.e., the limiting angle a vessel's direction can make with the wind is about 70° (sailors divide a compass card into eight equal parts which they call *points* (*quart*); each point is therefore 11°30'; each point has a particular name. Inspection of the wind rose will immediately familiarize one with these denominations). Now, according to the ordinary wind direction at Cherbourg and the position of the planned dike, a vessel could almost never have put to sea through the western passage.

A dike was then planned, formed of two branches, one going towards Isle Pelée and the other towards Pointe de Querqueville, protected by a central fort and forts established in two localities. The dike was to stop 600 m from Querqueville fort, but later soundings showed that acting thus would have completely closed the roadstead, and the project was stopped in time. The eastern branch is 1100 m long, the western branch 2200 m.

To leave the roadstead into the outer harbor, vessels warp along using mooring buoys. These are buoys held by 2 or 3 anchors. The entrance to the outer harbor, which is 60 m wide, is too wide; there is therefore some agitation and especially a very violent undertow because the quays are vertical. The outer harbor has a depth of 10.00 m below low water, but in some

respects this great depth is useless, because in the channel leading to it, at low water in some places there is only 4 to 6.00 m of water. By dredging these passages, the full advantage of the outer harbor's depth could be realized.

Toulon. This is the most considerable port in France after Brest. The roadstead of Toulon is natural and possesses all desirable qualities; it is completely closed to the mistral and open to the S.E., a very advantageous arrangement, for it is always with easterly winds that one arrives in France; the opposite occurs at Marseille. Under Louis XIV, the Toulon roadstead only presented a small commercial port. The full importance of this locality can be understood, and Vauban laid out the new basin. The roadstead could be further enlarged by building a dike over the entire portion of the passage where there is not sufficient depth for vessel passage. This would shelter 200 vessels. Two streams flowed into the Toulon roadstead, where they could bring sand. Vauban diverted the first into the cove preceding the passage, but the annual deposits of this small stream, *l'Égouttier*, form in its own bed, and as it is dry in summer, they are easily removed. For the other stream, Vauban thought there would be no drawback in letting it flow into a portion of the roadstead where there was not enough water for vessels to anchor, adding the sands, of not very considerable volume moreover, that it carries.

Vauban's port was still insufficient. Establishments were built for the immersion and all the work on timber. At this moment, fifteen covered slipways are under construction. Finally, the arsenal must be enlarged and establishments created so that steamships can easily be refitted and take on their coal, which is always a considerable affair.

Algiers. The old port of Algiers was formed by a dike built by Kheireddine and maintained at great expense to connect the city with the island opposite. The open roadstead was exposed to the northerly winds, which are very violent, and especially to the terrible undertow caused by the steep adjacent coasts. To build a port, Mr. Poirel proposed joining the extremity of the island formerly joined to the city by Kheireddine to the unnamed rock, then building a second dike connecting the land to the Roche Al Sifux. The port thus planned would first have been too small; next, it was rightly objected that vessels coming from the north would be obliged to turn sharply and beat against the wind; if moreover they missed the entrance, they would arrive over rocky ground full of reefs, where they could not anchor and where they would infallibly be lost. Mr. Rany proposed another layout. He suppressed Mr. Poirel's large mole. Once inside, vessels would no longer need to beat against the wind (still assuming a northerly wind). But his port would have been even smaller than the other, and the entrance would have presented this other drawback: that vessels, after passing the first jetty, would run a great risk of not entering the port and being dashed against the second. Mr. Raffeneau de Lille presented another project. He enlarged the port by moving the dike back towards Fort Balazonn. This dike, going to the Roche Sans Nom, turned back towards the city by means of two successive angles. The 50 to 60 m of the first project's dike already built were used, then it was extended, making the extension form an angle of 175° with the completed

part. To create calm in this passage, Mr. Raffeneau proposed covering it with a dike 400 m long, but this dike, already very costly as it would go to depths of 30 m, could still only shelter one or two vessels. To remedy this drawback in various modifications to his original project, he proposed lengthening it until the end of the pier head was on the line from the unnamed rock to Cape Matifou, then finishing his first dike which stopped at the unnamed rock; the portion of dike built by Mr. Poirel would then have been more harmful than useful. Depths of over 40 m would have been encountered; the enormous expense required for this construction can be imagined, and even then a very large number of vessels would not have found shelter behind this immense dike. Finally, Mr. Bernard proposed, and it was adopted, to move back even further towards Fort Balazonn to take advantage of the great depths thus enclosed within the roadstead. In addition, the entrance is to be protected by a mole roughly parallel to Mr. Raffeneau's, but starting from the beginning of the already built dike, connecting to it by a circle of 330 m radius, and then extending seaward for about 200 m. The ends of the pier heads always being in a straight line with Cape Matifou, these dikes, besides the forts to be established on the pier heads, will be protected by the fire of Fort Balazonn and by the two other batteries established on the shore. The passage will still be 300 m wide at its narrowest point and can be negotiated without difficulty.

Construction of Moles.

The first study to be undertaken before starting the construction of a mole, a dike, or a jetty is that of the locality where it is to be built. A sounding plan is needed; for this, contour lines are drawn. To survey a profile, its direction is first fixed by means of two landmarks, then in calm weather, one goes offshore to 3 or 4000 meters with a boat propelled by a suitable number of oars, usually making 4 knots. Having reached the farthest point of the profile to be taken, one positions oneself in the line of the landmarks, gives a determined number of strokes, lets the boat drift, and sounds. This operation is quite delicate: it is not easy to seize the precise instant when the lead touches the bottom, nor to take the average of the wave oscillations. The same number of strokes is given, and the same operation is repeated heading towards land. It is understandable that this method of operating is quite approximate. To make it more accurate, for example every 5 stations, the boat is fixed in the line of the landmarks by means of three grapnels, one on the right, another on the left, the other astern. Then two observers placed on shore at the ends of a determined base take bearings of the boat and can thus accurately plot its position. On the other hand, on the boat, the angles *DCS*, *DCS′* can be measured, providing several checks for the operations carried out on shore (fig. 23).

The use of instruments can be avoided by using three boats; two are placed in alignment with grapnels. To each is attached a chain with knots. This chain is tightened with a small winch until it is tangent to the water surface. The length and sag of the catenary are then

known. The ordinates can be determined, then the sounder is moved to points fixed on the chain. This gives a very accurate plan of the bottom.

Dikes can be made of rubble of all sizes, natural or artificial blocks, solid masonry, or lattice masonry like the ancient moles in the Gulf of Pozzuoli, or timber framing. Finally, floating moles held by anchors have been executed. As these different modes of execution are found in great works already executed or currently under construction, the particular study of each of these works seems to be the most suitable approach to follow.

Cherbourg Dike. Mr. de Cessart had proposed making the Cherbourg dike by means of large wooden cones which were to be sunk next to each other and connected by chains at their top. These cones were to be 60 feet high, 60 feet at the top, 140 feet at the base. They were to be filled with rubble stone up to the low-water line; above that, with mortared masonry. The first cone was sunk in 1784. Before the second cone could be sunk, as there had not been time to do the mortared masonry, it had been filled with rubble. A storm broke the pieces forming the top of the cone and scattered the blocks all around, so that fearing not to be able to seat the second cone at the foot of the first, it was sunk 30 fathoms away. The same accidents happened to this cone and the following ones. The sea always broke the upper part; shipworms successively attacked the parts exposed to air and water. Finally, after sinking 18 cones, which, too far apart, produced little effect, this very expensive system was abandoned. The interval between the cones was filled with medium-sized rubble, giving the rubble mound slopes of 3 base to 1 height on the seaward side, and 45° on the landward side. But on the seaward side, they made one of 6 base to 1 height. Work was then abandoned. Mr. Cachin thought that by using more considerable blocks, 2 to 3 m in size, the sea would no longer move them. He then made rubble mounds with stones of this dimension on the crests on the landward side, then arranged them in different places on the other side, with smaller stones. The sea still raised the slopes according to different inclinations and piled up the stones in front of the continuous mound of large stones formed downstream to a height of 2.00 m above high water. The final slope was 2 base to 1 height between high water and low water, 6 base to 1 height between low water level and 5 m below, and 3 base to 1 height. Below 5 m, there was no disturbance in the rubble mounds.

On the central part of the dike, Mr. Lamblardie built a granite fort, 70.00 m long and 3 m high above lowest low water. On this completed structure, a test load of 23,000 kg was placed using rough rubble; there were only slight settlements. As the rubble mounds, which held well for one wind direction, changed position for another, and as on the other hand the portion in mortared masonry held well except for some cracks which caused no serious problems, it was decided to build the dike in masonry from lowest low water level up to 3.00 m above highest high water. It was difficult to work at this level, which was uncovered for only a few hours a year. Mr. Virla had the idea, on the seaward side, of using roughly close-fitting fir boxes placed slightly in front of the future masonry, which men wedged and seated as best they could by entering the water. They were quickly filled with concrete and covered with nailed-down lids.

On the landward side, a small rubble enclosure was made; then, at low tide, barges were brought and concrete was poured between these two dikes. This concrete was poured working forward; it was poured dry and made to descend by pushing it forward. It did sometimes happen that at the following tide, only washed-out stones were found. It is underneath that this washing-out occurs. It is produced by water siphoning through the dike's blocks. The effects of this siphoning were much feared. Some executed parts were destroyed; it was seen that the washing-out stopped 0.12 or 0.15 m from the surface. Moreover, the water was perfectly calm under the concrete layer; all internal agitation had been damped by the passage of water through the interstices of the rubble mound onto the concrete layer. The masonry is being raised with granite facing; the top is 2.00 m above the highest seas; only two courses and a parapet 2.00 m high and 2.00 m thick remain to be placed. It is hoped that within four years the entire dike will be finished, except for the forts on the two pier heads.

The large blocks used for the construction of the Cherbourg dike come from the Roule quarry. In Mr. Cachin's time, stones were loaded onto a trolley (*binard*) in such a way that the stone's center of gravity was on the axle. The block was embarked onto strong pontoons which, if there was enough water, came to be grounded at the appropriate place. In the opposite case, the pontoon anchored as close as possible to the grounding site. The block was lifted vertically, then by means of sheerlegs (*bigues*) placed on the already completed portion of the dike, the block was hauled to the place where it was to be sunk.

Mr. Virla had a railway laid from the quarry to the loading point. The blocks are loaded onto flat wagons and thus brought almost onto the pontoon.

Port of Algiers. The old jetty built by Kheireddine was, as we have said, exposed to violent undertows, and to prevent its complete destruction, the Moors were obliged to spend considerable sums each year. It was in very bad condition at the time of the French occupation in 1830. Mr. Noël was responsible for repairing this dike. He succeeded by carrying out under-building repairs. In these works and in those that followed for the repair of the mole, it was recognized that blocks of 3 to 4 m^3 would not resist the movement of water. Mr. Poirel had the idea of making a concrete casing as at Cherbourg, but by using bottomless boxes; the sea always penetrating underneath through the interstices of the rubble mound would have washed away his concrete. He made boxes with a tarred canvas bottom, the canvas fitting fairly exactly onto the bottom, and several of these boxes were sunk. The construction seemed fairly solid; however, after some time, settlements occurred in the underlying rubble mound. Cracks appeared in the concrete mass, causing fear that the whole work might be lost. Nothing of the sort happened; once the settlement occurred, the concrete blocks did not move further. It was then thought to make the jetty with concrete blocks large enough that the waves could not lift them. By throwing the blocks pell-mell, the advantage was a very large number of interstices through which the sea was, as it were, filtered, calming down very quickly. Mr. Poirel had rectangular boxes made on site, measuring 3.40 m by 1.50 m by 2.00 m, thus having a volume of about 10 m^3. They were filled with concrete; the formwork was left for 8 days in

summer, and 15, 16 days in winter. The block had, at its lower part, two grooves made by means of two small wooden molds placed at the bottom of the box. During casting, a chain was passed through these grooves. These chains were attached to other chains by means of shackles, and by means of jacks each worked by four men, the block was lifted 0.50 m off the ground, and a flat wagon was moved underneath onto which the block was loaded. The loading point was an inclined railway on which the loaded wagon was rolled, care being taken to hold it back by strong cables wrapped twice around wooden posts. Finally, the wagon arrived onto a kind of pontoon formed by two large barrels; it was attached to a strong frame connecting the barrels and taken to the sinking site. One of the chains was released, the block fell, and the wagon remained attached to the raft. As long as there is sufficient water depth, the blocks are sunk; thus, when there is no more depth, when the dike connects to the land, the block is brought along the entire length of the completed part and launched like a ship. If blocks cannot be brought in this way, a very simple method consists of stacking sacks each filled with 0.05 m^3 of concrete and made of a very loosely woven fabric. The mortar passes through the fabric, and the sacks bond perfectly together. The expense is about the same as with tarred canvas bottom boxes, and work can proceed much faster; each sack costs only 0.50 to 0.60 francs.

Rubble mounds of artificial blocks cost 30 francs per cubic meter.

In concrete sacks: 50 francs.

With tarred canvas bottom caissons: 60 francs.

Blocks at water level do not resist wave agitation and are overturned unless they are overloaded with a considerable weight of masonry, 2 to 3 m thick. For slopes, that which the sea gives to the construction is usually adopted, 2 base to 1 height on the landward side, and 1 base to 1 height on the seaward side. These constructions are cheaper than those using natural blocks because of the smaller volume required. Thus, natural blocks cost only 7 to 8 francs per cubic meter, but 5 to 6 times more are needed. It was thought a considerable economy could be achieved by building the part situated 8.00 m above sea level with small blocks; this would present no drawbacks if no construction were built on top of the dike, but as one is always raised more or less high to install batteries, there is an undertow against these vertical walls, a new wave produced, and dangerous scouring and considerable settlements could occur. If therefore small materials are to be used, care must be taken to face them on the seaward side with a sufficient thickness of large materials so as not to expose the small materials forming the core of the dike.

Construction of Fort Boyard in the roadstead of Île d'Aix. The interval between Île d'Aix and Île d'Oléron is too great to be defended by the batteries established on these two islands; the entrance to the Charente was not protected, and these circumstances allowed the unfortunate fire-ship affair. Napoleon keenly desired that this passage be defended, and a plan was made to establish a battery near the Boyard bank situated in the middle. A rubble mound was to be made using the largest blocks obtainable; they even managed to bring one of 14 m^3,

and in one campaign, two courses were raised on the rubble. But a storm destroyed everything and lowered the mound to low water level, leaving only the 14 m³ block. Thus the size of blocks that would have been needed was seen, and construction was abandoned. The great development taken by steam navigation has made it more necessary than ever to defend this passage against any surprise, and construction of this work has been resumed. As the old rubble mound had become covered with shells and mud, it was decided not to touch it and to build on top of it. But there are parts which are only uncovered at the great equinoctial spring tides, i.e., about 4 times a year, others only at the great monthly spring tides. For the latter, the following procedure is used: a mason's workshop is prepared in advance; materials are brought on pontoons, and at the moment the sea uncovers, small walls 1.00 m high and thick are immediately raised, forming boxes about 5 m on a side, all with cement setting in a few minutes. At subsequent tides, concrete is poured into these kinds of boxes, but a surface is never left without covering it with cement. In the 1842 campaign, more than 400 superficial meters of this construction were done, and nothing has moved although there have already been several storms. As for the parts that never uncover, they will be made with concrete sacks thrown working forward and stacking them. Only the first course of these sacks is slightly washed out between tides, but by taking care always to remove the last layer placed, perfectly continuous blocks will be obtained; the fabric disappears, the fibers being soluble in lime. As soon as the level of the old mound is reached, a granite facing will be applied, and the body of the dike built in ordinary masonry. To proceed faster, successive courses will be advanced in steps, so as to have several in progress, and for all this masonry, the system of boxes used will be continued, taking care never to leave a concrete surface exposed to the sea without covering it with cement.

The difficulty of making joints in dimension stone masonry is well known. Masons, whatever one does, use wedges, or if the stones are laid on a bed of mortar, it is either too dry, in which case it does not adhere and the stone only rests on a few points, or too soft, in which case it flows out all around. The very simple machine whose drawing is given on plate J (fig. r) and which was used at Toulon to bed more than 3000 cubic meters, remedies these drawbacks. The stone is first laid dry, then lifted 0.15 to 0.20 m. A workman quickly spreads a sufficient layer of cement, and the stone is lowered back parallel to itself. For vertical joints, cement is placed in the cavity made to allow passage for the lifting tongs, and it is forced into all joints with a rammer.

The moles whose construction we have previously studied were intended either to create calm, as at Cherbourg, Algiers, or to serve for coastal defense, as at Fort Boyard. In the Mediterranean, where the water level can be considered constant, moles only need to satisfy one or the other of these conditions, or both combined. In the ocean, the tidal phenomenon adds to the difficulties of entering a port. It is by means of jetties that these new difficulties are most often overcome. Suppose a beach; between the high-water mark and the low-water mark, there are certain spaces, sometimes considerable (over 1000 m). If a port is to be established, it will almost always be built beyond the high-water mark. Suppose the port is

excavated; to establish a communication from the port to the open sea, a channel must necessarily be dug, whose assumed horizontal bottom is level with that of the port. For coasting ports, the width of this channel varies from 20 to 30 m; for major commercial ports, 40 to 50 m; for military ports, 70 to 80 m. As it is necessary to give a port a small width for a great length so that vessels can be alongside the quay, if a channel were simply dug, as we have said, all the wave agitation would penetrate the port and it would be impossible for vessels to remain there.

Moreover, such a channel would soon be filled, for they are generally dug to a depth such that wave agitation is not felt at the bottom. Now, shingle from both sides of the channel, finding a depth of only 1 to 2 m and consequently agitation everywhere, and therefore being in motion, would encounter a great depth and calm and settle immediately, and scourings could not remedy this silting because they would not be guided in the channel and would spread out on both sides. Finally, vessels would always run the risk of touching bottom to right or left, and over the whole length of the channel would be obliged to maneuver with buoys, an operation always long and sometimes dangerous to carry out.

These disadvantages partly disappear by means of two vertical, or nearly vertical, jetties which enclose the channel and whose top is below the highest water level. The wave will die out completely in this channel if, at intervals, the jetties are cut by openwork structures communicating with closed basins whose bottom rises with a very gentle slope. In all ocean ports where there is not water at all tides, jetties are used.

When there is a good rock bottom, the simplest and most natural construction is a double masonry jetty. Their length is determined by the port depth and the shore slope; their height by that reached by the highest seas, increased by at least 2 to 3 m. We have spoken of their spacing; as for the width of each, as they are actual towpaths for ships, it is made 4 to 5 m. So that haulers are not exposed to the waves, parapets 1.50 m thick and 2.00 m high are built. At intervals, there are cannons or mooring bollards.

To build below low water level, cofferdams or concrete works can be used. In ports with large tides, cofferdams reaching above the highest tides could evidently not be used. Half-tide cofferdams are used, i.e., pumping must be done at each tide to work for the rest of the time. To undertake such work, one must be sure of being able to pump out in 1½ hours, 2 hours at most, in order to have 4 hours to work. Moreover, a large number of workmen must be available, and the site arranged so that during high tide all the work for the following low tide is prepared. The use of cofferdams with pumping is always expensive.

Concrete works are preferable. First, two rows of close-fitting piles are driven, connected by wales slightly above low water level. The interval between these piles is dredged down to solid ground with spoon or bucket dredgers. The dredging machine can be placed either on beams that rise with the tide, or on a flying scaffold built above high water level.

As soon as a certain length has been dredged, at low tide, concrete is poured there, working forward, not throwing it into the water. By operating thus, the laitance is always pushed forward of the slope that forms. When there is a certain amount, it is removed with sheet metal buckets moved along the bottom. As soon as a level above low tide is obtained, the rest of the jetty is built by working at low tide, the facings in dimension stone, the rest in filling.

Jetty facings are nearly vertical. Mr. Colonel Emy proposed curved facings joining with the bottom and rising vertically. Mr. de Baudré used this profile at St Jean de Luz. It is difficult and expensive to execute and probably of little use, for if it is true that the wave encounters less obstacle on a curved wall, on the other hand it will rise higher and the effects of its fall will be more formidable for the lower portions. And as it is very difficult to prevent mortar from being washed out of joints, the lower portions of the structure, which have no foundations to which they are solidly attached, are carried away. The surest means of diminishing the violence of the waves is to protect the foot of the jetty with rubble mounds of blocks that the sea cannot move. Concrete blocks manufactured on the jetty itself and thrown at its foot could be used successfully. Moreover, jetties with straight facings executed at Granville, Cherbourg, Le Havre, and which resist perfectly, answer Mr. Emy's objections.

The leeward jetty must be longer than the other for two reasons. If they were equal, a ship which, in heavy weather, had rounded the leeward dike would run a great risk of being dashed against the other. Next, it must serve as a siltation spur; shingle deposits in front of it, and only when they have filled all the space in front of the jetty do they pass it and form a point bar (*poulier*) in the channel. If care is taken, by means of dredging, not to let this space reserved for shingle fill up, their introduction into the channel need not be feared.

To obtain the maximum effect from scourings, Mr. Lamblardie proposed giving the jetties a convex shape towards the side from which the shingle comes. This arrangement would be very suitable if one were certain of not being obliged to extend the jetties later, but as on the French coast this always happens (at Dunkirk the jetty is 2000 m long), the jetties would end up having completely contorted shapes. The best thing is to make the jetties straight. Moreover, in the case where the shingle passes the pier heads and scourings become necessary, they produce with the jetty the curvature proposed by Mr. Lamblardie.

For the openwork structures interrupting masonry jetties, it is appropriate to space the frames 2.5 to 3.0 m apart; closer together they would produce a slight undertow that would hinder ships in the channel. The bottom of the basins placed behind the openwork structures, which are intended to lengthen the wave, must be laid and raised following the gentlest possible slope up to high water level.

Timber Jetties. When the bottom is mud, masonry constructions would be very expensive, even if they could be built, which would always be very difficult. Timber jetties are then resorted to. Some of these jetties are very old; they are found especially in the north. The jetties of Flushing consist of two parallel rows of close-fitting piles connected at different heights by wales. The space between these piles is filled with rubble, gravel. It was thought to

reduce the expense by replacing the close-fitting piles with frames, onto which planks were nailed to form sheeting. The planks were first nailed inside the frames, thinking the greatest thrust would be from the inside outwards, coming from the gravel, but before the boxes were filled, the sea had carried away the planks. They were then nailed externally and held very well. These dikes were originally faced up to 2.00 m above the towpath. It was recognized that there was a great advantage in leaving an openwork space of 2.00 m below. Hence, half-sheathed jetties. As shipworms always attacked the wood and the sheathing emptied, the work had to be completely redone.

Today, completely openwork jetties are used. The jetty built at Dunkirk can be cited as a model of its solidity. It may be recalled that about two years ago, the steamboat *Le Véloce* collided with this jetty without the paddle box and wheel being completely torn off, and without the jetty suffering any damage. It was executed in the following manner: to face scour holes, *fascine* mattresses were used. A mattress of *fascines* all placed in the same direction is built on shore. Then, on top, a second row of fascines is placed at right angles to the first. A four-layer assembly is thus formed, each layer set back from the one below by 1.00 m, 0.50 m, 0.50 m, and 0.50 m, and pierced by stakes. Care is taken to arrange the site so that the whole mattress can be floated by a spring tide. It is brought to the appropriate place and sunk by means of additional weights. To hold it in place, piles are driven through it, pinning it, as it were, to the ground. This done, the frames built on shore are brought by floating and put in place. In these frames, tenons are avoided. Only housing joints with fish plates are used. When a piece needs replacing, the fish plate is unbolted and the piece to be replaced is slid out. The deck (*tillac*) is not made of close-fitting pieces; the planks forming it are spaced 0.02 m apart; water arriving on this deck is filtered instantly. Mooring bollards are placed in the middle of the deck; in this way, mooring is easy, and a free passage is available on half of the track.

The fascine work is completed by placing a new mattress, however giving the whole a curved shape. Then long stakes are driven through the entire mass. The stakes are connected by wattles so as to form a series of longitudinal compartments. These compartments are filled with well-shaped rubble stones placed on edge. If the dike thus made left too large a passage for the waves, a packing piece could be bolted between two frames.

Floating Jetties. For great depths, fixed jetties could not be undertaken without enormous expense. It was thought to resist the action of waves by means of floating openwork structures; it has long been noticed that in an area enclosed by floating booms, agitation was much less considerable than outside. It was imagined to construct a series of wooden frames connected by 4, with angles crossed. The whole is set afloat and moored short by one side (fig. 24). The wave is filtered twice in passing through such a system, and almost all agitation disappears; it seems these dikes have succeeded in England. Mr. Tyler asks 400,000 francs to establish 300 m of such dikes at Marseille. To shelter ships in quarantine, a dike was built between the islands of Pomègues and Ratonneau. When the wind comes from the S.E., the agitation is much greater than before the construction of this dike, due to the undertow. As there is 15 to

20 m depth, a fixed jetty cannot be considered. The placement of a series of full-bodied floating breakwaters on the lee side is then proposed. The form adopted by Mr. Tyler presents drawbacks: as the only effective means of preserving this wood from shipworms is still to sheathe it with copper, the system becomes very heavy and is almost entirely submerged; moreover, it cannot be boarded, which would present great advantages. Perhaps the following form would satisfy the conditions of being more buoyant and accessible. A simple raft 3 m wide and 1 m deep, which would be perfectly stable, could be traversed by a series of vertical pieces connected horizontally. These pieces would serve to divide the wave and at the same time to moor vessels, for one could then board the raft (fig. 24). Moreover, this form has not been executed.

For mooring sinkers, buoys, floating dikes, etc., the English have replaced ordinary anchors, always expensive, with others much cheaper and which seemed to hold well in the ground. This method of anchoring cannot be used at depths greater than 10 m, as one must be able to turn this kind of corkscrew with a driving rod (fig. 25). A cheaper and more convenient system than all of these would perhaps be to manufacture a concrete block of 12 to 15 m^3, traversed by an iron piece protruding as a ring, which would be easy; the chain linked to the buoy would be attached to this ring, and the block would be submerged. Such a system would cost 600 francs at most.

General Layout of a Port.

Once the channel is crossed, one arrives at the outer harbor, also called the grounding port (*port d'échouage*). The outer harbor must have the same depth as the channel, and at least three times its width, because first, the wave agitation, already diminished by the openwork structures, must die out completely in the outer harbor; and second, sufficient space is needed so that vessels alongside the quay are not inconvenienced by those arriving, and vice versa. As for length, it must be sufficient for a ship arriving before the wind to lose its way, and at the same time for a large number of ships to be able to stay there. For a large commercial port, it should not be less than 400 m. If the depth of the outer harbor were greater than that of the channel, there would be a chance of alluvium, and scourings would not produce their full effect. Moreover, it is good that the bottom of the outer harbor be mud or sand, because at low tide, vessels that take the ground and which, at the moment they start touching, are lifted by the wave and consequently fall back, should not encounter too hard a ground. The ground must also not be sloping, otherwise vessels would risk damaging their hulls. If the bottom were rock, it should be allowed to silt up.

The first part of the outer harbor bears more particularly the name of outer harbor (*avant-port*), the second that of grounding port (*port d'échouage*).

The shores must be lined with quays, for a large number of vessels, especially coasters, prefer to stay in the outer harbor.

Masonry quays must have a fairly considerable thickness, for the thrust of the earth is further increased by the weight of goods deposited on the edge. The average thickness is usually taken as half the height. They are founded at low water level, and the masonry rises to 1.00 m above high water.

On a rock bottom, masonry quays cost 2000 to 2100 francs per linear meter, as they are sometimes very high. As quays are exposed to a very large number of shocks, they soon become damaged over almost their entire height. So in many localities, the decision has been made to cover them with a timber facing. This consists of simple planks nailed close together on crosspieces, replaced when rotten. For all these reasons which make masonry quays so expensive, timber quays are sometimes preferred. A row of piles is driven at 1.50 m center to center; their heads are fastened by two walings, between which close-fitting sheet piles are driven. It is good to use squared piles. The Dutch take the greatest care in driving sheet piles. They first drive two rows of piles, cap them with timbers between which they place the close-fitting sheet piles. By driving a whole row together, especially in the case where the sheet piles must prevent the arrival of water, as for the floor of a lock, these precautions are less indispensable when it comes to resisting earth thrust. Behind each pile, another is driven, connected to the first by two walings, and on the first pile rests the crosspiece on which the facing will be nailed. This crosspiece is supported by a strut abutting the rear pile. All the frames are connected by two wales, one placed behind the rear pile and consequently embedded in the part of the ground not liable to slide, which gives great resistance to the whole system.

On quays, mooring bollards are placed at intervals. For constant mooring, rings embedded in the masonry are preferable. These rings should be bronze to be protected from the action of water; cast iron would be brittle, wrought iron too oxidizable. Galvanizing would not hold due to friction. They must be made of bronze or wrought iron covered with bronze.

Around the outer harbor, other constructions, equally indispensable in a port, are grouped. A retaining basin with a lock for making scourings in the channel; except for Brest and Cherbourg, no port would be without this. The retaining is done at high water springs, and scourings at the corresponding low waters. The lock must be as close as possible and opposite the channel.

One or more wet docks, whose purpose is to keep constantly afloat fine-lined vessels that cannot take the ground. Water is sometimes maintained at variable heights, sometimes at a constant level; the latter is most often that of mean high tides. Wet docks do not need great width. On each side, one row of vessels alongside the quay and a second parallel row to immediately occupy the places of those leaving the quay. Besides these 4 files, enough space for the movement of those arriving or departing gives a total of 70 to 80 m. Wet docks for steamships must have much larger dimensions; transatlantic packets of 450 horsepower are 20.00 m wide and 87.00 m long, including the bowsprit. Assuming the same conditions for this dock as for the previous ones, allowing 120 m for turning, it is found necessary to give them a

width of 200.00 m. It is important to have a separate dock for steamships because, besides the width of the necessary locks, they require special supervision and care.

As for wet docks, one, and often two locks are needed (in case one is being repaired). It is appropriate to give them a certain length in order to make the most of their construction. As, on the other hand, passage through them is tedious due to congestion, certain limits should not be exceeded; 500 m is a suitable length.

To these constructions must be added all the establishments necessary for the construction and repair of vessels: slipways, dry docks, timber ponds, and considerable coal depots within reach of steamships.

How to group all these establishments in the same locality, what are their relative requirements? Most often, one is constrained by the locality, but let us here assume a clear site and a port to be built, and seek what the general arrangements could be. The jetties forming the channel are cut by openwork structures; opposite is the scouring lock with the retaining basin; to the left, the outer harbor. Opposite are the commercial or government docks, communicating with each other; the entrance to these docks must be as close as possible to the end of the channel so that vessels can reach them during slack water, which is sometimes very short. As steamships can maneuver much more easily, their dock can be placed at the end of the outer harbor, and this arrangement will place them farther from the town, supposed to be behind the other docks. Between the wet docks, one can assume 70 to 80 m, either if these docks are immediately at the water's edge with a street in the middle, or if there are two quays with warehouses in the middle. Between the high-water mark and the outer harbor, on alluvial, sandy, low-value land, slipways and all other establishments of this kind will be placed far from dwellings. Doubtless, such a port does not exist and perhaps never will, but at least these brief remarks show the most essential exclusive conditions that one should seek to realize.

Wet Docks.

In the Mediterranean, the water level is approximately constant; it is not the same in the ocean, and except for some exceptions like Brest, vessels which at high tide find more than sufficient draft would be obliged to take the ground at low tide, if by particular means they could not be kept afloat. A large number of vessels can take the ground, but for fine-lined vessels and for most state vessels, this operation would be very fatiguing and could cause serious drawbacks. At the end of the channel, however shallow its depth below low water level might be, a place could be excavated to a depth such that vessels entering with high tide would still float when the tide had withdrawn. This arrangement, executed at Cherbourg, allowed vessels of low tonnage to enter at any time of the flood. Those of ordinary tonnage would enter at half tide, and only large vessels would be forced to wait for high water. The basins would then need to be small in area, for since their level must be the same as that of high water, an

immense volume of water must pass through the channel between one tide and the next. If these considerations are applied to St Malo, where the tide range is 14 meters, to a wet dock of 80 hectares area, it can be seen that over 150,000 cubic meters would have to pass through a lock in one hour, resulting in such a great velocity that maneuvering would be absolutely impossible.

We spoke in the previous lesson of the dimensions of wet docks. As for water depth, it depends on the nature of the vessels they are to receive. For commercial vessels, the maximum depth of a wet dock is 7.00 m. For state vessels, it is 9.00 m. The largest ships of the line draw only 8.10 m of water, but a small depth of water must always be left under the keel so that, due to oscillations resulting from agitation in the basin, they cannot touch. In addition, a small depth margin must be reserved to be able to make scourings in the outer harbor.

Wet docks communicate with the outer harbor by a lock composed of a floor and two side walls (*bajoyers*). These side walls are straight or inclined according to the closing method adopted. Most generally, mitre gates have been used. For large openings, floating caissons have been employed. The use of rolling caissons has also been proposed. The latter, perhaps suitable for large openings, are probably not likely to be frequently applied, since the invention of steamships driven by propellers gives hope that it will not be necessary to further increase the openings of wet docks.

As the construction of locks presents a great analogy with that of dry docks, for which the conditions of watertightness are even more imperative, everything that will be said for dry docks will apply to locks.

Mitre Gates. The mitre gates of wet docks present, except for dimensions, the greatest analogy with navigation locks. The projection of the mitre sill is between ⅕ and ⅙ of the opening.

Mitre gates are composed of two leaves which abut against each other, also resting on the mitre sill and the hollow quoins.

Each leaf essentially consists of a heel post around which rotation occurs, a mitre post, and horizontal ties connecting the two posts. Planking is nailed onto these ties. The dimensions of the timbers used are very variable; for commercial wet dock locks, which are not more than 14.00 m wide, the timbers are roughly 0.40 m by 0.35 m. For large wet docks, where gates can be up to 21.00 m wide, single pieces of sufficient cross-section are not available. Double pieces are then used, the construction of which we will discuss later.

Ties. Considering the static pressure in isolation and supposing the sea level drops to the mitre sill, it is seen to increase from zero to the bottom of the leaf. One is therefore rationally led to proportion the resistance of the timber framing parts to the load pressing on them and consequently to space the ties more closely at the bottom. For calculation, it can be assumed that each tie carries the water slice between horizontal lines dividing the ties into equal parts. But a great many circumstances must modify these results; the pressure of water

acting directly on the planking is transmitted by it to the ties, and often very unevenly. On the other hand, the shock of waves, that of boats against the upper part of the gates, the considerable weight of these gates, require that great resistance be given to the upper tie. Finally, experience shows that it is towards the middle that gates have to support the greatest stress, and it is appropriate to give the middle tie the same scantling as the two outer ties. If the others are not equally spaced, they should not be much closer together in the lower part than in the upper part.

On the heel post, on the mitre post, on the upper tie and on the lower tie, rabbets are made the thickness of the planking planks deep, and the latter are nailed there, as well as onto the intermediate ties.

The assemblies of the pieces composing the gates are generally made with tenons and mortises. The ties have a tenon which enters the mortises of the posts; the lower crosspiece should have only a half tenon. The same would apply to the other lower crosspieces if they were not too close together, for they would weaken the posts at their foot. Sometimes double tenons have been used. Mortises have been placed sometimes on the right, sometimes on the left. These systems should be rejected because in both cases the piece is cut into above and below the neutral fiber, where the fibers have to support greater stresses. Generally, a housing joint is made at the assemblies, and the whole piece is let into the posts by two or three centimeters. This system is perhaps not good in that it diminishes the resistance of the posts by the full amount cut away for the housing. In some gates, the housing is only partial; it is then a reinforced tenon.

Brackets and Stirrups. When the gate is open, the heel post is the only piece supporting all the others, which tend to separate from it due to the effect of their total weight, which can be up to 50 tons, or by that of their weight diminished by the weight of the volume of liquid displaced. The assemblies of the ties with the heel post tend to work, to open up at the upper part and to tighten at the lower part, while for those of the ties with the mitre post, the opposite effects tend to occur. These movements are somewhat opposed by iron fittings, 0.10 to 0.12 m wide and 0.05 to 0.03 m thick. Brackets or stirrups are used. Brackets are generally applied to two ties and one post, and on each side of the gate, these pieces are bolted to the post and the ties. Stirrups encircle the post and are bolted only to the tie, but then the post must be cut away over three-quarters of its perimeter; moreover, it is difficult to prevent one of the two pieces from projecting over the other, thus multiplying the chances of water leakage.

Sway Brace. But all these iron fittings would not prevent the gate from nosing, i.e., tending to tip over by turning in a vertical plane around the heel pintle. The most effective means that can be used against this movement is the sway brace, an indispensable piece in a lock gate. The sway brace bears on the heel post and on the upper tie, which is more advantageous than having it bear on the lower crosspiece and the mitre post.

The sway brace is assembled with a housing joint and 2 or 3 notches on the heel post. It is cut out where it meets the ties, which are similarly cut out; then the two pieces overlap. 0.15 to

0.16 m of full section is left on the sway brace, whose total thickness is about 0.30 m. To fix the sway brace to the ties, bolts are sometimes used, but, especially for the middle ties, this arrangement would be very fatiguing. It is better to place small sway braces between the ties and connect them to the main one by bolts. They then form a kind of fishplate which adds to the solidity of the system.

Diagonal Straps. Finally, to further prevent the gates from sagging, double wrought iron diagonal straps are used, joining the lower end of the mitre post with the upper end of the heel post. They thus resist by tension while the sway brace resists by compression. To tension the straps suitably, they can be made in two pieces ending with opposite-thread screws. These screws enter a nut which, when turned, tensions the two parts of the strap.

Pintles. Pintles must be made of bronze, the metal that best resists seawater and friction. It is advantageous to finish the male pintle with a convex surface of fairly large radius.

Collars. The collar must support the gate in different positions. It is most often formed of two hinged parts which encircle the heel post. The bronze collar has two or three branches embedded in the masonry and carefully connected to its wrought iron anchors. These anchors can advantageously be placed below the coping stone of the side wall. They are traversed by wrought iron pins placed vertically in the masonry. One of its anchors is embedded in the direction of the closed gate; one cannot be placed in the direction of the open gate, because it would be too close to the exterior face of the side wall; it is inclined a little more into the masonry.

Rollers and Jacks. Rollers have sometimes been used to relieve the heel post. These rollers present no great advantage, for to function well they would need a large diameter, and under the gate there is only a void of 0.20 m at most. The lower tie would then have to be notched, which would imprudently weaken it. Some of these rollers were simply cannonballs traversed by an axle. These axles rested on lugs attached either to the mitre post itself, or to the tie and very close to the post. The rollers did not turn; there was very considerable friction at the lower part; the gates warped and only advanced in jerks when maneuvered. As, moreover, what matters is that the leaf does not remain long in a fatiguing position, it is much better to substitute jacks for rollers. These are iron rods threaded at their upper part. These rods fit into a small socket fixed to the floor. When the gate is to be maneuvered, the jack is turned. It no longer bears; the movement takes place, and as soon as the gate has reached one of the positions it must occupy for a long time, the jack is lowered and the gate then rests on two supports.

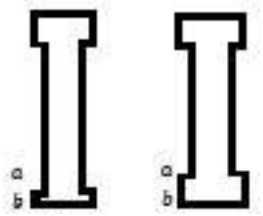
Built-up Beams. We have seen that for certain gates, it is impossible to find pieces of sufficient scantling. Those used are then formed of two parts. The contact face is approximately in the middle of the total thickness, where the fiber that is neither compressed nor stretched is supposed to lie.

For this system to resist well, the two pieces must be perfectly interdependent and adhere to each other as well as if the piece were continuous.

The pieces are assembled by bolts and notches. The bolt holes and notches must be executed with great precision, the notches especially. When the piece is subjected to considerable stress, the hard parts of each piece penetrate the soft parts of the other; there is sliding of the superimposed faces, and the double piece no longer resists like a single piece. This drawback is remedied by means of small sheet metal shims.

Each notch must have sufficient length so that it is not carried away by the pressure exerted against the small face. Thus, when a rafter is assembled onto a tie rod, the latter must be extended for a certain length, otherwise the pressure would cause the wood to split. This resistance of wood parallel to the fibers is not well known. It can be approximately evaluated at one-tenth of the resistance to rupture perpendicular to the fibers.

To arrive at this result, Mr. Bernard made a series of experiments which consisted of the following. He took wooden cylinders of equal thickness, cylindrically reduced by the same amount in their middle. The heads of the lower parts had only variable heights *a b*. This cylinder was fixed by its upper part to a strong crosspiece by means of a collar with lugs passing under the upper bulge.



On the lower bulge was placed a similar collar to which a large box capable of holding up to 10 cubic meters of water was suspended. By means of two taps, the weight could be varied continuously and easily appreciated. Experiments were carried out successively on cylinders, starting with the one whose height *a b* of the bulge was the smallest. As long as the ring forming this bulge was torn off by sliding along the cylinder, longer and longer bulges were taken until one was reached such that it was the starting cylinder that broke transversely under the load. By this experimental method, for a constant cross-section, the surface on which sliding tended to occur was successively increased. Thus, the surface for which the resistance to sliding was equal to the resistance to transverse rupture was reached.

All of Mr. Bernard's experiments led him to the result that the first of these resistances was 10 times weaker than the second. It is evident that in practice, pieces should not be subjected to loads exceeding a quarter or a third of those producing rupture.

Two pieces of wood can also be joined by means of metal or hard wood dowels, of lignum vitae for example. The two pieces are drilled with an auger; then, once the hole is made, on the face that is to be the contact face, these holes are enlarged to 2 to 3 centimeters in diameter and 5 to 6 cm deep. These holes are spaced 7 to 8 cm apart, placing them alternately on each side of the piece's axis so as not to make the effort bear on the same longitudinal fiber. Lignum vitae cylinders are driven forcefully into these holes. The other piece is placed on these cylinders, and as the holes correspond perfectly, the cylinders can be made to enter the second

piece, which thus adheres perfectly to the first without the scantling having been in any way diminished.

Sliding Sluices (*Ventelles*). In wet docks, the level of the retained water is ordinarily that of mean high tides. Consequently, on days when the tide exceeds this mean height, the gates open easily and, as it were, by themselves. But on days when the tide does not reach this height, to open the gates the effort exerted on them by the level difference between the retained water and the tide of the day, which can amount to 0.50 m, would have to be overcome. These drawbacks are remedied by means of sliding sluices (ventelles), by which the equality of level between the wet dock and the outer harbor is restored.

The projection formed by the grooves in which the sluices slide should be reduced as much as possible. If this projection were very considerable, one would be forced either to increase the depth of the recess, or to cut a chase in the lower part necessary to house it.

Sluices are very useful for making small scourings at the foot of the gates; they remove the mud that ordinarily deposits there. These scourings are done at low tide with the water from the retained basin. When there are deposits inside, which moreover is rare, on days of high water, spring tides, a scouring could be made from the outside to the inside. Moreover, when alluvium is somewhat considerable, it becomes necessary to make scourings tangential to the gates. A conduit is made, as has just been done at St Malo, in the side wall at 2 or 3 meters depth, connecting the two sides of the gate. Scourings can then be made in both directions with the greatest ease. Only, as it would be difficult to have valves that could resist well in both directions, unless using metallic valves constructed with great care, a double valve is placed in the conduit.

The sluices of lock gates are ordinarily placed between the two lower ties and near the mitre post. They could not, because of the sway brace, be placed near the heel post, and it is even appropriate then to place the diagonal strap on the end of the last but one tie.

Sluices are raised by means of levers, screws, or jacks. By using a lever acting in the plane of the gate, moving a portion of toothed wheel which engages in the rack of the sluice rod, the valve can be raised instantly, while with jacks it takes half a minute, and with screws a full minute. The first means is the most advantageous in that scourings are more effective the quicker they are.

Planking. The planks are 0.08 to 0.10 m thick. They are assembled in rabbets made on the outer ties and on the posts. Without making these rabbets and simply nailing the planks, they would be very easily torn off. The planks are parallel to the sway brace or vertical. The latter strengthen the gate by transmitting to the upper tie, always of large scantling, a part of the pressure they support. The sway brace must then be cut into as many pieces as there are intervals between ties. Diagonal planks support the upper tie and serve approximately the same purpose as the sway brace, but they do not bear equally.

The rabbets, before receiving the planks, must be carefully tarred, and all joints caulked.

Semi-floating Gates. By using northern fir, attempts have been made to make the weight of a leaf approximately equal to that of the volume of liquid displaced. As movement only takes place at high tide and when the leaf is in place, it rests on the jack. The fatigue the heel post has to support is thus notably diminished.

Curved Gates. It is becoming more and more difficult to find timber of sufficient scantling for the construction of straight gates, and the price of this timber is increasing enormously day by day. It was then thought to make curved gates, for which pieces of smaller scantling can be used. It is known that curvature plays a very great role in the resistance of pieces. A straight piece placed on two supports and uniformly loaded bends and takes a deflection which varies with the weight. If a curved piece is placed between two abutments and uniformly loaded, the center lowers and the haunches rise. Suppose, for example, a piece 15 to 20 m long placed on two abutments. Divide it into 9 arcs. When it is loaded, it will be observed that the deflections of the three middle arcs will diminish, while the deflections of the arcs of the end parts will on the contrary increase. There will thus be two kinds of nodes situated at two-thirds of the total length which will not change curvature. The middle part of the piece will therefore behave like a piece three times shorter, consequently presenting a much more considerable resistance.

Attempts have been made to bend timber with steam, but this process does not always give good results; steam destroys part of the sap mucilage. Now it is precisely this sap that gives suppleness to the fibers, allowing them to slide over one another, so that wood subjected to a stress bends before breaking, while wood that has been subjected to the action of steam becomes brittle, and for them rupture follows almost immediately upon the slightest bending. Curved gates built at the port of Brest lasted 30 years and are being replaced by new ones exactly similar. The scantling of most pieces does not exceed 0.40 m; the planking is on the upstream side. Stirrups and brackets are replaced by copper forks placed under the ties. In the old gate, the ties were assembled with double tenons; the mortises were left slightly larger than the tenons, and to fill the void, the two branches of the fork were introduced. The rod placed thus under the tie was fixed there by means of bolts. As these bolts cut into the piece vertically, this arrangement was without doubt safer and much better than that which consists of placing the bolts transversely.

Cast Iron Gates. The reasons we have spoken of, the scarcity and high price of timber, have led to the study of the use of cast iron and wrought iron in all constructions and also in lock gates. Cast iron gates with timber planking were tried at Cherbourg, but they did not succeed and had to be replaced by wooden gates. In the Annales, January 1842, Mr. Dufresne gave a description of these gates. Here are some passages.

The ties are of cast iron. They are hollowed out and fitted with a wooden lining on which the planking is nailed.

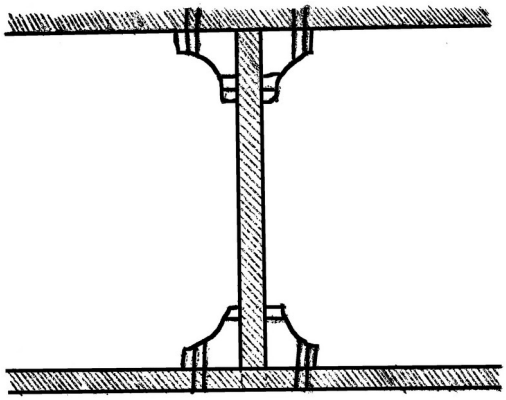
The heel and mitre posts are also cast iron; the former have the shape of a hollow half-cylinder, the latter are flat and covered with a wooden lining cut as a wedge according to the angle of the mitre so as to effect a complete closure.

These gates were not to have sway braces. A simple diagonal strap was to keep them rectangular.

The fitting of the pieces had been done with extreme care, and when after installation all supports were removed, the gates settled only by an imperceptible amount.

But the shocks produced by waves in the outer harbor soon broke the ties, and after some attempts to replace them with wrought iron, it was decided to remake the gates entirely of wood.

Moreover, these results occur everywhere. Cast iron should never be used for pieces exposed to shocks; in all machines, only the stable, immobile parts can be left in cast iron; the active moving parts, piston rods, driving wheel axles, etc., must always be wrought iron. The use of wrought iron tends to become more and more general, and its price diminishes, so to speak, as that of wood increases. Iron costs 30 to 40 francs per 100 kg. For 50 francs, one would be sure of having the best. Ships have been made of sheet iron, lock gates have been made of cast iron and sheet iron for canals; everywhere the use of sheet iron has presented great advantages. Moreover, it can be handled with the greatest ease. Two sheets of iron joined by a series of rivets present a perfect bond. When the sheet iron pieces are not to be lapped, they are joined by a strap and two rows of rivets. With the aid of angle irons, all possible arrangements can be obtained by reproducing them with sheet iron. Angle irons are pieces drawn through a die. They are placed in the free angle of two pieces to be joined in an invariable manner, and fixed to each of them by a series of rivets. It is known that it is impossible to rivet onto cast iron.



Lock gates constructed entirely of sheet iron would weigh only 12 to 15 tons, consequently much less than wooden gates. As for oxidation, it would not be much more to be feared than in wooden gates, which contain considerable quantities of iron.

Wrought iron and also cast iron pieces can, it is true, much more than wooden pieces, be made so that the material is distributed precisely where it is needed; and this distribution of material is perhaps the most important thing in the phenomenon of material resistance. Suppose a metal blade fixed at its two ends; load it. It will bend extremely. Instead of one blade, take two superimposed, load them with a double weight; almost the same bending. But instead of putting them in contact, keep them at a distance by very thin shims, *St. Andrew's crosses*; in a word, prevent the relative movement, the sliding of one blade over the other. We will have a system that will hardly bend under considerable loads. Take an example: two pieces, one 5 mm

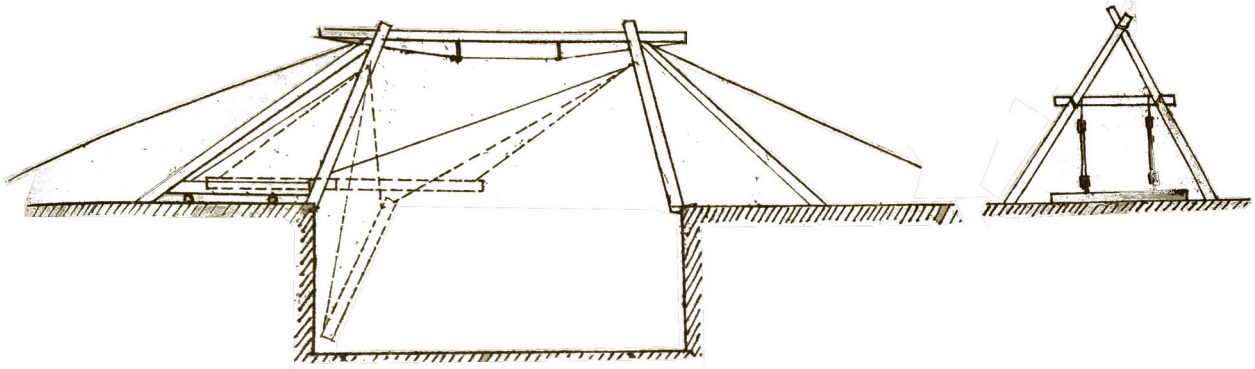
thick, the other 2 mm. Their resistances to bending will be as 5^3 to 2^3 or as 125 to 8. Instead of the 2 mm piece, take two pieces each 1 mm thick and keep them spaced 3 mm apart, so that any sliding is impossible. We have not used more material than before, and we will have two pieces whose resistance to bending, instead of being in the ratio of 125 to 8, will be in that of 125 to (5^3 - 3^3) or 125 to 98.

But sliding must always be prevented; hence we have sought to highlight this necessity in the manufacture of wooden pieces formed of two pieces placed one on top of the other. A closed system of two parallel iron strips joined by perpendicular crosspieces would present no solidity. Thus, the 3 parallel arches of the Austerlitz bridge, joined by normal joints, could slide freely relative to each other, and there were numerous ruptures. The surest means of avoiding these movements is the use of St. Andrew's crosses or tangent circles, which amounts to the same thing.

Wrought iron has this remarkable property: if a wooden piece is loaded, there is no increase in deflection when the load increases, and as soon as there is bending, there is rupture. This property gives full assurance for the use of wrought iron, as long as the force that iron in tension or compression can support is not exceeded; one will be sure that there will be no deformation.

Lifting Gates. The weight of a lock gate leaf for a wet dock varies from 25 to 50 tons. This is therefore a very considerable weight to move, so lifting gates always presents some difficulties. When the lock is dry and there is time, the gate can be assembled in place. The heel post is first fixed in the pintle and the collar. The ties are brought in and supported on trestles until the mitre post is placed. All pieces can be lifted by a shears, and this method is the simplest but by far the longest.

The leaf can also be placed fully assembled, but there are still two methods. All the pieces of the gate can be brought into the lock chamber and assembled on the floor. To put the leaf in place, it must undergo four main movements. 1° it is lifted by rotating it around the lower edge; 2° it is raised above the floor; 3° it is brought vertically above the pintle; and 4° it is lowered.



The gate is seized by means of two slings attached to two tackle hooks. Each tackle consists of 6 falls, 0.04 m in diameter, of new white hemp, and can carry 18 tons (a 0.015 m diameter rope can support 1500 kg before breaking, but it should only be loaded with one-third of this

weight). On the quay, two lines are strongly moored with guys; two capstans act on the hauling parts of the 2 tackles, and the gate is made to undergo the first 2 movements we have spoken of. This done, a lateral tackle is attached to one of the large tackles, and with a third capstan, the heel post is brought vertically above the pintle and allowed to fall.

Finally, when pressed for time, one can dispense with assembling the gate on the lock floor. On each side wall, a pair of shears legs is placed, formed for greater security of four pieces assembled at the top. These shears are held by guys and joined by a long fir pole (*sapine*). To prevent bending of this long piece, a chain and two cast iron pieces can be used to reinforce it very solidly. The completed leaf is brought on rollers between the four posts of the shears. The gate, by means of slings and tackles, is raised very little above the ground; then, by acting on the tackles of the shears placed on the opposite side wall, the whole gate is brought outboard. Then it is gradually released on the capstans, and the gate descends by itself. By winding the rope around a bollard, it can be paid out as gently as desired and the leaf placed without any shock. This mode of lifting, which requires more gear than the previous ones, presents great advantages. The system is set up simultaneously for both gates. In two or three days, with 6 capstans and 6 tackles, a pair of gates can be placed, and all other systems to be used, for it suffices to lift the leaf a few centimeters off the ground; much less force is then needed to move the leaf once suspended by the slings.

Operation of Lock Gates.

To open the gates, a rope can be used attached to the end of the mitre post and wound around a capstan fixed on a spindle embedded in the side wall. This capstan is placed upstream of the gate on the line perpendicular to the leaf in its mean position. Consequently, on the chord of the arc described by the mitre post, about 2.50 m from the edge of the side wall. In this way, the traction, initially inclined to the leaf, becomes normal to it, then inclined in the opposite direction by the same amount as before.

To close the gate, another rope is also attached to the head of the mitre post and wound on a capstan placed on the opposite side wall and downstream of the gate. As long as the gate is open, this rope must hang across the lock. It then hinders vessels entering or leaving.

These drawbacks led to the abandonment of ropes. They were replaced by a rigid rod hinged to the mitre post and to the ends of which a fairly slack rope is attached so as to make one or two turns around a capstan. By turning the capstan either one way or the other, the rope is pulled and consequently the rod, which in one case pulls the gate to open it, in the other pushes it to close it. The capstan is the same one used to open the gate in the first system.

This arrangement was used in many localities and with success, but it wore out many ropes. From this rod, one was easily led to a cast iron rack engaging with a 6-toothed pinion, and it is on this pinion that the men assigned to the operation act. It then becomes necessary

to support the rack in front of its pinion, for nothing prevents it from moving away. To do this, a vertical post is placed in front of the capstan and on the bisector of the angle formed by the normals to the extreme positions of the rack. Placed thus, this post, while holding the rack, leaves it some play and allows it to pass from one extreme position to the other. But it happens with this system applied to large gates that the rack cannot stay straight, that it bends and engages poorly with the pinion. Racks of wood and iron could easily be made, less heavy than cast iron ones and which would resist better.

But all these methods have the drawback of pulling the gates at the top; they tend to warp. When they have rollers, this effect is almost inevitable. For large gates like those at St Malo, it can be said that it would be absolutely impossible to operate them in this way. Here are the main arrangements adopted for these. In each side wall, two vertical wells are made, one for opening, the other for closing the gates. For the first operation, the well descends to 2.77 m from the floor. In this well is a vertical shaft carrying two drums on which two chains wind, which grip the mitre post at two different points. To close the gate, the opposite side wall must be used, but when the two gates are open, the chains used for this operation must not remain stretched across the lock. They must descend almost vertically in line with each side wall and lie on the lock floor. They must therefore be of great length. They could not be wound on an ordinary shaft. A capstan with whelps must then be used, whose projecting parts successively engage the recessed parts of the chain. The chain then, after passing over this capstan, passes over a horizontal-axis pulley and descends into the well. It is understandable that when a capstan is turned for one of the operations, the capstan used for the other must turn in the opposite direction.

To reduce the number of men needed for this operation (16 would have had to be put on the capstan bars), a geared capstan was used, but it will take 15 minutes to open the gates. This is a considerable time, but for gates of this size, it was very difficult to combine all advantages.

After all these details relating to the construction, lifting, and operation of gates, let us take them in place and see if they can function alone and maintain the water at a constant level in the wet dock whose entrance they close. Unfortunately, this is not so: when the swell coming from the open sea is at all strong and strikes against the gates, they cannot resist this effort; they open, then immediately after, the flood retreating, the gates close violently; consequently, shock and vibration of all the assemblies. Attempts were made to prevent these movements by joining the mitre posts with a wedge, this arrangement was good. At the top of the gates, they remained tight at this end, but they opened at the bottom almost as much as before, where the same shocks and vibrations occurred.

Then dogs were used to support the gate over its entire height; this arrangement was adopted at Dunkirk. The dogs are actual gates without planking which come to abut against the main gates when they have closed, and which fold back behind them into the recess when they are opened.

The dog post does not rest directly on the gate, but on wedges or cleats fixed to the ties. The ties of the dog gate are placed in the parts corresponding to the voids of the gate, so that the cleats do not prevent the gate from closing completely and the whole takes up as little space as possible in the recess.

To prevent the dog from escaping following a somewhat strong shock imparted to the gate by the wave, it carries at its upper part a horizontal rod which passes over a latch fixed on the gate and into which a wedge is passed. In this way, the two gates become more interdependent.

Despite the dogs, the gates are still very fatigued, and at St Malo, for example, this arrangement would not offer enough resistance. Flood gates are then placed at the head of the lock, exceeding the height of the highest known tides. They differ in no way from the ebb gates we have spoken of, only they are mitred in the opposite direction.

Lock gates unfortunately often need repairs. By placing only a single pair of ebb gates at the entrance to a wet dock, one can imagine what drawbacks would result from their removal or closure; all vessels would be obliged to take the ground or change basins, which often would not be possible. And for a single piece of wood to be replaced, one would be deprived of all the advantages of such a considerable construction as a wet dock. So everywhere two pairs of ebb gates are placed, so that a complete lock must present two ebb gates and one flood gate. The Dutch have sometimes used two flood gates, but this is not at all necessary. Since it was necessary to reduce to putting two pairs of ebb gates, it was thought to utilize this arrangement by staggering the water level they are intended to maintain. First, this would be very difficult to achieve; infiltrations through the first gate would soon fill the space between the two, which is always small, so that the second gate would bear everything, or very active surveillance would be needed to maintain the levels at suitable heights with sluices. Finally, and this is the greatest objection that can be made to this system, neither of the two gates is designed to carry the total load. Suppose one is under repair, what use would the other be? Thus, one should not hesitate to use two pairs of gates capable of resisting the whole load alone. The utility is so great that the expense is more than compensated.

Of Dredging and Scouring.

The sea brings shingle, sand, and mud. Shingle, if the windward jetty is sufficiently extended, does not enter the port or forms a point bar at the end of the channel, but rarely in the outer harbor. Mud goes everywhere; the slightest agitation suffices to keep it in suspension for several days in a row, so it penetrates all parts of the port.

To get rid of shingle, it must be removed as it arrives. A certain space is reserved for it in front of the longer of the two jetties forming the channel, a kind of trap where it deposits. At first, this idea was daunting, and it was thought impossible to remove all the shingle brought

by the current in a year. It was believed that much more came than actually does. At Le Havre, 10,000 m^3 are removed annually, and it is regretted that there is not more.

This shingle is used as ballast. 40,000 m^3 would be needed for the needs of Le Havre commerce. By arranging such a shingle trap, the greatest facilities for removal are available. At low tide, tipcarts arrive and are loaded; roughly constructed barges can also be used, brought at high tide, grounded, and filled at low tide. At high tide, they float again and are taken away. This method, at first glance, might seem preferable; it does not appear to be so. These barges, however rough, require a fairly considerable capital outlay; their maintenance is expensive; much cordage is used; while tipcarts, on the contrary, require almost no capital or maintenance. At St Malo, the spoil was removed with barges. Contractors have offered to do it cheaper using tipcarts.

In parts that do not uncover, other means must be used. When there is only 2.50 m to 3.00 m of water, hand dredges can be used. The spoil is immediately deposited on the boats where the workers stand. The use of these dredges has the drawback of fairly expensive labor, but also requires no capital.

For great depths, it is appropriate to use large dredges moved by winches turned by men, or by steam engines, or any other motive power.

On a boat, two horizontal shafts driven by some means can have two ropes winding onto them, which set two large dredges in motion, so that when the rope wound on the main shaft raises a loaded spoon, the other wound on the second lowers the empty one. When the loaded spoon is above water, a boat is brought underneath, a valve at the bottom of the spoon is released, and the load falls. Spoons bringing up 1.50 m^3 to 2 m^3 per grab can be used. For great depths, this is still the dredge that gives spoil at the cheapest rate.

Bucket dredgers are also used. This is an endless chain turning on a square shaft; every two links is a sheet metal bucket. The only precaution to take is that when the ladder carrying the endless chain is inclined, the buckets should go from bottom to top. In this way, a bucket arriving at the bottom of the ladder, and at the moment it is about to turn to go up, encounters some obstacle, it lifts the ladder slightly and no drawback results. Whereas if the movement were in the opposite direction, a bucket which, at the moment of turning at the end of the ladder, encountered any obstacle, would only press the ladder onto the ground in trying to overcome it, and could break the ladder or itself. This direction of movement is moreover necessary for discharging the spoil into the receiving buckets.

This spoil removed by bucket dredgers is received in boats placed underneath. It is important to distribute the load as uniformly as possible throughout the boat. For this, the discharge chute through which the buckets empty is arranged so that the spoil is thrown into the axis of the bucket. The spoil is then distributed symmetrically. The boat only needs to be given a translational movement. Moreover, these buckets must have a large capacity, for there is always a considerable loss of time when replacing a full boat with an empty one.

The mud or gravel thus dredged is used as fill, as ballast, or dumped offshore. In the first two cases, the loaded boats are brought to the quay and unloaded like ordinary goods. Advantage can then be taken by placing on the boat a series of skips which are filled as if the boat were flat. The loaded boat arrives under a loading platform; the skips are seized by a crane and loaded onto trains which, by means of railways, take them to the places where filling is carried out. When there is any considerable filling to be done, this is how it must be done, for shovel transshipment, especially for mud, is very expensive.

To dump spoil offshore, hopper barges are used which are opened, and the whole load falls. The places where these deposits are to be made must be chosen with great care, for one must be sure that the current, aided by the wave, will not bring them back into the port. But generally, currents are well determined in position, and by choosing very deep places that are on the line of no current, one can be safe.

A bucket dredger can dredge 2.50 m^3 of mud per horsepower per hour. These results are at least applicable to the machines used; until now, 10 horsepower has hardly been exceeded. It is much more advantageous to give the buckets a slow movement than to make them run quickly. By acting thus, there would be shocks that would shake the machine and considerable losses of power. Now, by using stronger machines, if the same buckets were kept, they would have to be turned faster, but we have just seen what is bad about this arrangement; or the size of the buckets would have to be increased, but the resistance offered by the ground would immediately increase in a considerable proportion. It would be imprudent to exceed 20 horsepower; and in any case, two 10-horsepower machines would produce much more than one 20-horsepower machine.

It is known that for the sea to be able to transport shingle or sand, the current and the wave must concur to this effect. It was then thought that by artificially agitating the water, the ebb current could be used to remove mud. At Rochefort, a considerable deposit had formed at the entrance to the dry dock. Mr. Hubert thought of dragging over the bottom a kind of harrow moved by a windmill. The mud was lifted and carried away. This mill, established over 30 years ago, still exists and always works successfully.

Thus, by aiding the current, the same effects can be made at its exit into the channel as those produced by it on arrival, aided by the wave. Its speed can be increased by forcing it to pass between two pontoons. A small head then forms upstream, and the current established downstream carries away the sands and even the shingle. A similar process has been used successfully to dig channels in the sand masses that annually hinder navigation on the Garonne.

We have seen that in certain localities, at Le Havre for example, alluvium can be disposed of by annual dredging. But to count on the success of these dredgings, the locality in which they are to be carried out must be well known. One must be sure that the space reserved for these deposits will be large enough that a single storm cannot fill it, for then the shingle would pass the windward jetty and enter the channel. Not only the channel would then have to be re-

dredged, but also the sand trap, for without this, the sand and shingle, no longer encountering, before arriving in the channel, a depth greater than that at which they travel, would not settle before the channel and the passage would be constantly closed.

Thus, in some ports, the great abundance of alluvium prevents leaving it to settle in a determined place without drawbacks. For these ports, following a storm, the entrance to the channel can, so to speak, be instantly filled. Instantaneous means are then needed to be able to reopen it as quickly as it was closed. The method of aiding the ebb current by artificial agitation, as we saw done at Rochefort, has been little used so far. The most effective method consists of scourings. Water is retained at high tide in a basin and allowed to escape only at low tide. Thus, both a movement and a very great agitation are formed, and the alluvium is lifted and carried away.

Scourings were originally done with the waters of wet docks. Sluices in the lock gates were opened, then this first means being recognized as insufficient, openings were made in the side walls. But the wet dock was almost always at the back of the outer harbor; the latter alone received the first effects of the scouring, and it was only by virtue of the rather weak rise in level occurring there that the water flowed into the channel after having lost all its energy. So, if scourings done by means of wet docks have the advantage of being economical and cleaning the outer harbor, they have the drawback of agitating the vessels lying there and being insufficient to clean the channel. Thus, the creation of separate retaining basins for scourings was necessitated. They were then placed as close as possible to the channel so that the current still had all its energy when it encountered the main mass to be expelled.

In the various retaining basins built specifically for scourings, the tendency has been to make them higher and higher and to give the outlet orifice the largest possible section. It can indeed be conceived that a small mass passing over an obstacle of a certain extent will have used up all its living force after a very short time, while an enormous mass animated by great speed will strike with great force all the alluvium up to the end of the channel.

At Le Havre, the Florida basin, which has 7 hectares, is insufficient. At Ostend, at Dunkirk, retaining basins of 30 hectares produce good results, especially at Dunkirk, where the scouring lock is near the end of the channel. At Boulogne, the retaining basin has 60 hectares, but this is too much, and 30 hectares will almost always suffice, even if partial scourings operated simultaneously in the outer harbor with the wet dock basins cannot be combined with the main scouring. We shall see what advantages can be derived from the combination of these arrangements.

Suppose the scouring lock directly opposite the channel and the outer harbor placed laterally. As soon as the lock is opened, the water rushes into the channel, but at the moment it reaches it, there will already have been a very great loss of useful work, for besides the eddies that always accompany the contraction of the stream, this stream meeting tranquil water will form an immense eddy at the entrance to the outer harbor. Next, a very large quantity of water spreading into the outer harbor will cause its level to rise until the outflow

through the channel equals that through the lock. All this water received by the outer harbor will therefore be lost, for when the scouring is finished, either the rising tide will soon reach its level, or if it has time to flow out through the channel, it will be at too low a speed to obtain any result.

But if, a little before opening the scouring lock, small scourings are started in the outer harbor, its level will rise and a current will begin to be produced at the entrance; then by operating the main scouring, the stream will no longer meet tranquil water, but a current, much weaker it is true, and the eddy will always be considerably diminished. Moreover, the level of the outer harbor will no longer rise at the expense of the retained water, and a much larger volume of water will pass over the alluvium at high speed.

Retaining basins must be fed by the sea; it is true that small streams from the land can also be used for this purpose (this would be the only means of making scourings in the Mediterranean), but this presents several drawbacks: several scourings are necessary at the time of syzygies; the basin must be filled very quickly, and the ordinary flow of streams would not suffice. Moreover, these streams should not be received after storms, as they would silt up the basin. In short, there must be an absolute necessity to take these streams for one to decide to bear all the drawbacks they bring.

Scouring locks have to support enormous pressures when the outflow begins. At the opening, a depression and considerable contraction occur, continuing downstream; then there is a backwater, and the slope continues fairly uniformly. But the water passing over the floor forms violent eddies and tends to produce scouring holes often 5 to 6 m deep, and which have even been 12 to 13 m deep in Holland. It follows that scouring locks must have powerful foundations, protection aprons, and upstream and downstream aprons. It is appropriate to give these two parts as much length as possible to resist the effects of horizontal-axis eddies.

The effect produced by scouring locks evidently increases with their width. Most often, it is given 8 to 10 m. Some have been built 12, 16, and even 24 m wide, but this offers great difficulties.

Scourings are done at the time of spring tides, a little before the sea has ceased to fall, so that the scouring is finished as soon as it rises again. The most ordinary effect is to deepen the channel to a depth of 1.00 m to 1.50 m below low water. Sometimes, but very rarely, 2.00 m below this same level has been reached. So no result would be obtained from scouring done in the Mediterranean.

When the sea is calm, the current issuing between the two jetties spreads and dies out at a short distance. All the alluvium then deposits in a fan in front of the entrance, which is completely closed by a circular ridge. The scouring would consequently have produced nothing, and a storm must come to agitate this whole mass of alluvium, which forms a true bar, and cause a large part of it to pass downstream of the channel (relative to the current). The other part does re-enter the channel, but more than half is always disposed of. Unfortunately, the

sea cannot be controlled, and it often happens that the port entrance is closed for several days in a row. A passage must then be opened at all costs. At low tide, with harrows, bars, this whole mass can be stirred, and the ebb will get rid of it a little, but the means is not very effective. It is better to recommence scourings, only the spreading upon leaving the jetty must be prevented and allowed to occur only farther out, where great depths are usually found.

The most effective means consists of using guide booms (*guideaux*), which Lamblardie père used successfully.

These are simple rafts formed by four longitudinal beams as strong and long as possible, joined by crosspieces placed close enough in pairs to form squares with the longitudinal beams. In these squares, 0.30 to 0.40 m on a side, and on only one edge of the raft, vertical piles are placed, whose depth is regulated by means of a rack. The guide booms are floated at high tide, then at low tide the vertical pieces are adjusted so that the whole guide boom rests on the one hand on the side without piles, and on the other on the ends of these piles. Several of these guide booms are placed in succession and opposite each other. In this way, the channel is extended between two inclined surfaces as far as desired.

However, guide booms do not always succeed, and many times one does not know how to clear the port entrance. Various means have been proposed, all quite expensive, none of which have been executed. Among others, a floating reservoir has been proposed, a vessel containing 1000 to 1200 tons, to be taken to the very place where a scouring is to be done; the deposits, struck so closely by a not very considerable mass but animated by great speed, would be carried away.

If a vertical plane of sufficient height could be raised in front of the deposit to be removed, there is no doubt that a fairly weak agitation of the sea would completely clear it away, for it is a certain and constant fact: steep coast, deep sea, the wave arriving against a vertical wall rises to very great heights; there is considerable undertow, consequently deep scouring at the foot, and in this case, it would be the scouring that would be the desired goal.

Means of Closing Scouring Locks.

The conduit through which water escapes from the retaining basin must be able to be opened and closed at will and as quickly as possible. For the first scouring locks built, wooden valves were used. These valves were raised vertically by means of two racks. Without this precaution, they would have borne more on one side than the other, and it would have been impossible to make them work. Despite this, this arrangement was still very defective. The grooves in which the valve had to slide could not be greased. Friction was 0.30 or 0.40 of the pressure, which was enormous. A considerable time was needed to raise the valve, and the first layers of water escaped before it was completely raised, and the scouring effect was singularly dampened.

To reduce friction, the Dutch fitted the valve with rollers which rested on the groove, but then the valve no longer fitted exactly against it; it let water pass. This leakage was prevented by means of a revolving post placed in a recess in the side wall on each side of the valve, pressing it against the side wall. The pressure could have been made even more energetic by taking a spiral arc for the perimeter of the post's cross-section.

Despite this, a certain time is still needed to operate these valves. Their whole weight, which is sometimes very great, has to be borne. Counterweights were then used, and much less force sufficed. An apparatus similar to that used for some drawbridges has sometimes been employed. Two strong Vaucanson chains carry at their ends a horizontal cast iron piece which moves on two curves; in this way, the system is in equilibrium in any position and can move very quickly, but it is very complicated.

For all these operations, and in general in all those where jacks are used, there is a great advantage in substituting the two-toothed pinion for the four-toothed pinion. First, when the two teeth are engaged with the rack, they act as a ratchet, and this is always a piece that can be omitted. Next, when a man turns a crank, he does not have the same strength in all positions; there are only two positions in which he can exert a considerable effort. Now, by using two pins instead of four, they can be arranged to be placed successively in these two positions. In many cases, it has thus been possible to use only one man for efforts which, with ordinary jacks, would require two.

After roller valves, valves rotating around a horizontal axis placed at the top, then in the middle, then the axis was made vertical. It was first a simple leaf with a recess and held on the opposite side wall by a dog or by a post which had one side larger than the other. In one position, it prevented the gate from opening, but when turned, the gate escaped.

A similar arrangement was reproduced for two leaves which do not meet and which come to rest against a post, one side of which is wider than the interval separating them, but the other side of which is smaller; by turning this post then, both gates escape, and quite a large opening can be obtained.

With gates thus arranged, there is no way to stop the scouring once it has started; the basin must empty. This presents great drawbacks. First, considering only the scouring itself, it is unnecessary; next, it is rare that retaining basins do not have another purpose at the same time. Old vessels, service vessels, etc., are put there. And then, once the scouring has started, an accident could occur which could become very serious if the scouring could not be stopped. With valves, one could close when desired, but they were too small, and moreover we have mentioned some of their drawbacks. It was thought to fix gates rotating around an axis placed roughly in their middle. On the larger of the two faces, a sluice is made of such size that when it is open, this part of the leaf has less area than the other. It is easy to see how such a system is operated. The gate is held by two dog posts similar to those previously described. The sluice is closed. The dogs are turned; the gate opens immediately, but it does not come to place itself exactly in the line of the current due to the considerable slope the liquid takes. If, when one

wishes to close, the sluice in the downstream part of the gate is raised, this part then having a smaller area than the upstream part, suddenly turns, and the lock is closed. Instead of a single gate, there could be two heel posts and three dog posts.

As retaining basins for scourings also serve as wet docks, they must be connected to the outer harbor. In several localities, it has been proposed, for reasons of economy, to have only one opening serving both for scourings and navigation. The revolving gates we have spoken of could not be used, as the passage they can leave free is much too small for navigation.

Mitre gates were then proposed, one of which would have a fixed gate in its lower part, but this system would offer very little solidity. The gate could have neither sway brace nor diagonal strap. They would constantly nose, or large rollers would have to be used; in any case, the gates would be very fatigued, and there would be considerable water leakage through the lower parts.

Another means of closure was executed at Gouda, in Holland. It consists of two systems of mitre gates at A and B (gates C are only to avoid losses due to continual pressure from the retaining basin). Gates A open by themselves and cause gates B to open. When water is allowed to flow out downstream through conduits D, filling spaces E, to stop the outflow it suffices to close the communication at D and open it at F; then the water pressure, filling spaces E, would return gates A and B to their original position.

In this system, the gates rub against each other; appreciable deterioration results.

Another system has also been executed in Holland which does not present the same drawback.

Each gate is composed of two leaves making a determined angle between them. When communication is closed at D and open at E, the gates remain closed because leaf B is larger than leaf C. When a scouring is to be done, it suffices to open at D and close at E; the water filling the spaces will flow out at A, and these gates will open by themselves. They operate well, but they have the drawback of being heavy, and it is very difficult to fix their heel posts to the side walls; these posts only bear on their pintle and collar; it is then good to make collars with three anchors.

Revolving gates are executed in three different systems, each about as good as the others.

1° There are 7 to 8 vertical uprights, including the heel post and the two end posts. Two end posts have rabbets in which horizontal planks are nailed on the upstream and downstream sides, covering the other uprights. Fishplates can be placed at top and bottom.

2° There is only a single planking formed of inclined planks placed in grooves between the heel post and the two abutting posts. Horizontal crosspieces forming fishplates connect the system at different heights.

3° Finally, the three abutting posts and the heel post can be connected by horizontal fishplates at intervals, but as such a system would present no solidity, the space in the fishplates is filled by a lining assembled with tenon and mortise to the posts. On these kinds of ties, vertical planks are nailed on each side of the gate.

Dry Docks.

Dry docks (*formes*), or graving docks, are enclosures, most often in masonry, intended for the inspection and repair of vessels. The grounding berths having been arranged in advance in the dock the first time it is emptied, water is let back in. Vessels enter afloat; immediately, the opening is closed, most often by a *door-boat*; a new emptying is carried out, and when, due to the lowering of the water level, the vessel has descended onto keel blocks, it is supported laterally by props placed on steps provided for this purpose in the masonry.

The emptying of the dock enclosure takes place either by draining the water outside, or by removing it with apparatus. In tidal ports, this drainage usually occurs by itself down to low water level.

The interior surface of a dock approximates that of the largest vessels for which it is built.

The main question in their construction is that of depth. It obviously depends on the draft of the vessels to be admitted; which draft is not the same if they are light or armed. Until now, it has not been ventured to fully ground a completely armed vessel, but at least the depth of a dock must be sufficient to receive the vessels for which it is intended when they are unloaded only of their water and artillery, which can be done in 24 hours.

So, first there is this draft; then under the keel, sufficient space must be available to work, to drive treenails, which requires at least 1.00 m, 1.20 m; then a floor 3.00 m thick. Depths of 11 to 12.00 m below the level at which the vessel entered the wet dock are thus arrived at. One can then imagine what immense difficulties such a construction must entail in a Mediterranean port; also, for a long time it was regarded as impossible at Toulon.

In 1773, Mr. Groignard undertook to build a dry dock at the port of Toulon. The ground on which this work was to be built first presents a layer of spongy mud containing shells, plant debris, and some parts of clayey sand. Its thickness varies from 5 to 11 meters. Below this layer is that commonly called *saffre*, which is a mixture of gravel and clay; its thickness is more than 50 m. The gravel found there comes from the mountains overlooking Toulon; so all the partial layers of which it is formed are connected to these mountains and offer a passage to all the freshwater springs flowing from them. The saffre is therefore eminently permeable; moreover, it is compressible: 36 piles 25 to 30 cm in diameter and 6 to 7 m long driven into an area of 36 square meters excavated 5.00 m below ground barely raised the ground surface by a few centimeters, the ground thus being compressed by an amount almost equal to the volume of the piles.

Mr. Groignard thought he could build on this ground without piling. At that time, caissons were still little known. It was he who first applied them on such a large scale. He proposed to build a watertight one large enough to contain the whole dock.

As it would have been impossible to build this caisson on land and then launch it, it was built on a raft; as this raft and this caisson were in themselves a considerable affair, it is useful to go into the details of their construction.

> "The raft, which was to support out of the water the weight of the caisson estimated at 2200 marine tons of 1000 kg, presented a surface 101.95 m long, 37.00 m wide, and was formed of a first lower layer of spars placed side by side laterally and edge to edge, 258 in number, having variable lengths from 19.50 to 26.25 m and variable diameters from 0.54 to 0.81 m. On this layer were laid transversely 23 rows of double upper stringers. These pieces, 0.65 m square, were joined by planks nailed externally. The rows of stringers were connected to the spars of the first layer by well-tightened lashings.
>
> The 22 intervals of the stringer rows, each 1.30 m high, were each filled with three rows of empty barrels called *pièces de 4* (about one cubic meter capacity). The barrel heads were capped with wooden crosspieces also lashed to the spars.
>
> All these barrels were hermetically sealed by cork stoppers covered with canvas. On the second row of stringers was laid a floor of northern fir, 0.108 m thick, with removable panels above the bungholes of the barrels.
>
> It was on this raft that, as would be done on land, the keel blocks or berths were built, formed of pieces of timber superimposed to the height and distance necessary to build, plank, and caulk the bottom and the lower zones of the rising sides of the caisson. When these sides were raised to 3.00 m in height and planked to 1.95 m, all the removable panels of the raft's upper floor were removed, and between one keel block and another, compartments or decks were made, the width being the same as that of the stringers on which they were built, and there were stowed 712,289 kg of pig iron or old cannonballs. All around the raft, in the excess of its width relative to that of the caisson, 52 other boxes were formed to place another load of 542,829 kg. These surcharges were intended to sink the raft until the bottom of the caisson reached the water.
>
> Before unstopping all the barrels to detach the raft from the caisson and make it sink, precautions had to be taken to hold it between two waters, and prevent it from descending loaded to the bottom of the sea, from where it would have been difficult to retrieve."

To this end, pontoons and flat boats (*gabares*) fitted with capstans were placed outside on each side of the raft, and attached to barges filled with water to balance the effort the beams

would have to make to lift the raft. 14 cables were passed under the raft, the ends of which were wound onto the capstans of the pontoons.

To unstop all the barrels at once, all the canvas covering the bungholes were attached to a single rope, so that by tightening this rope, the canvas and consequently the stoppers could be removed.

When the raft was completely detached from the caisson, the latter was floated to the place where it was to be sunk. The capstans of the pontoons and lighters were hove in to lift the raft uniformly and bring it back to the water's surface. This operation was not as successful as the immersion. The cables passing under the raft did not pull horizontally; the sides of the raft rose and came together so much that the central part of the raft was still submerged by more than four meters, while the sides emerged. However, the whole raft was dismantled piece by piece without great loss.

The bottom of the caisson was formed of floor timbers each composed of two courses of pieces 0.32 m square, placed vertically one on top of the other and bolted. They were spaced alternately solid and void, and connected by longitudinal stringers (*longuerines*) spaced 4.55 m center to center. These stringers, called keelsons, were formed of four courses of pieces also 0.32 m square. Three were placed side by side underneath, all were notched where they met the floor timbers and secured by bolts. In the intervals between the stringers, planks 0.11 m thick were nailed onto the floor timbers. It can therefore be seen that the keelsons projected from the caisson bottom. The walls of the box were formed in the lower part of close-fitting pieces 0.30 m thick in double thickness.

While the raft was being built, Mr. Groignard had the site of the dock excavated with dredging machines; he carefully sounded the bottom of the excavation, had it leveled by carrying out partial fills which he compacted with a rammer whose 11 m high stem received the blow of a monkey weighing fifteen metric quintals.

We have seen that the caisson bottom was not flat. It was necessary, on the bottom of the excavation, to dig the channels necessary to place the keelsons, and unfortunately it was impossible to give these excavations the exact shape of these pieces.

The caisson was successfully sunk. It was first loaded with rubble stone; then, to regulate the sinking well, it was finished by filling it with water. Piles were driven all around to moor it securely. Finally, to cause immediate settlement of the ground, the caisson was loaded with a weight of 50,000 tons. It had been calculated that the total weight of the masonry of a ship docked in the dock would only be 45,000 tons.

After six months, Mr. Groignard had the caisson pumped out. This operation was easy. Then the rubble was removed and gradually replaced by the masonry of the floor, built as an inverted arch. This done, the side walls were begun. When they had been raised 2.50 m, their weight caused the portion of the floor on which they rested to settle. Long cracks, gaping openings appeared throughout the construction, and water rushed into the enclosure. The side

walls had to be demolished. Mr. Groignard had trenches dug along the entire length of the floor, leading the water to a kind of well, and by means of 28 vertical chain pumps worked by men, he was able to put the caisson dry and restart the masonry. Several times the water returned. By multiplying the trenches, the construction was completed, accumulating water in the well, but they could not succeed in sealing the springs as hoped.

Mr. Groignard tried to confine them in a vertical well which he built in brick with excellent lime and pozzolana mortar, but the water broke through this masonry. Instead of brick, he used dimension stone; he had no more success. He finally took a bronze well, but the connection of the new masonry necessary for its installation with the already existing masonry could never be achieved.

Things remained there for 2 years. 120 m^3 of water came in per hour, and 200 men night and day were needed to keep the dock dry. Consequently, 400 men were needed on their feet for the functioning workshop and to relieve them. However, they preferred to resign themselves to these expenses than to do without a dry dock.

Mr. Caron, Director of Maritime Works at Toulon, had the idea of sealing the springs with concrete, which was beginning to be used. He had the well from which the water emerged carefully cleaned. A huge mass of concrete was formed around it, and at a given moment, a mass of men acting together threw all the concrete into the hole. For an instant, it was thought successful; for a few seconds the water was smothered, but immediately after, it forced its way through and all the concrete was violently projected; all the workers were covered with mud and lime. Mr. Caron, present at this operation, saw the means to make it succeed. He thought, rightly, that the water tended to come out by virtue of the level difference between inside and outside. He then had a vertical shaft made of planks around the hole. Water was let into the dock. When it had reached the outside level, a large mass of concrete was poured into the shaft. The water was calm, the concrete took perfectly, and when after a month the dock was pumped out, 0.9 of the water from the springs had disappeared. They have not returned, and today the little water that enters the Groignard dock in no way prevents it from functioning perfectly.

A single dry dock was insufficient for a port like Toulon, and the government requested the construction of two new docks. One was to have 0.45 m more depth than the Groignard dock. The other, even larger, was to be able to admit a ship of the highest rank, unloaded only of its water and artillery.

Should one proceed as Mr. Groignard had done? Firstly, the expense had been enormous: it had been 2,050,000 francs initially, not including subsequent expenses. The caisson alone had cost 700,000 francs, and at that time (1774) money had a value at least double what it has today. The initial lack of success of the construction could be attributed to the compressibility of the ground, which had not been sufficiently taken into account. Next, there had been no immediate contact between the ground and the caisson bottom because of the seven keelsons

projecting below the caisson. The voids imperfectly filled between these wooden pieces had offered passages for water under the caisson.

Means were therefore sought to consolidate the ground and to unite the construction well with the ground. To fulfill the first condition, the method used in Venice was followed. The whole site was interlarded with piles. Ramming does not have great power. The rammer, in sinking, always displaces neighboring parts, and in sum, one can hardly count on the action of the rammer extending to more than 0.60 m depth. By driving piles 1.00 m center to center, assuming these piles are 0.25 to 0.30 m square, it suffices that the radius of action of a pile be 0.40 m for the whole soil to be compressed over a thickness equal to the length of the piles. When driving piles solely to consolidate the ground, they must be driven small end first, whereas if piles are driven to reach solid ground, it is appropriate to drive them large end first.

After driving the piles, mud appeared in the excavation. There was no question of getting rid of it by dredging; the pile heads, more or less flush with the ground, would have stopped the spoons or buckets. Stones were simply thrown in and strongly tamped to make them penetrate the mud and thus form with it a kind of masonry.

To establish the construction, a true concrete cofferdam was formed, a floor 3.00 m thick and side walls also of concrete. Pumping was to be done and a masonry facing finished.

To enclose the construction, close-fitting piles 13.00 to 14.00 m long, driven about 3.00 m into the ground, were driven on three sides. Once the floor was poured, a means had to be found to form a double enclosure for pouring the side walls. One of these enclosures was the line of close-fitting piles. For the inner enclosure, a very light caisson was brought into the excavation and sunk in the middle. This caisson, which cost only 50,000 francs, was built on land in several parts which were launched according to the methods used for launching boats. To utilize curved timbers that were available, it was given approximately the shape the dry dock was to have, i.e., a flat portion 8.00 m long, terminated by two cylindrical portions of 8.00 m radius. This caisson was made of local piles costing only 25 to 30 francs per cubic meter.

Once this caisson was in place, the fourth side of the excavation was closed by close-fitting piles in front of the portion where concrete was to be; the rest of the opening was closed by a large watertight panel which closed the bottom of the last portion of the inner caisson.

It was a considerable undertaking to pour 14,000 m^3 of concrete, at a time when concretes were not yet well known. It had to be poured as continuously as possible. Nevertheless, after some trials, working day and night was abandoned; supervision was impossible, and it was decided, by raising the workshops, to work 16 hours a day.

The mortar was made of one part fat lime and two parts Italian pozzolana. It was made in a circular trough in which four wheels turned, driven by four horses. One grinding lasted 20 minutes and gave 1 m^3.

The concrete was made nearby. One part mortar and two parts broken stone were taken. A basket of mortar was taken, two baskets of broken stone were placed on top; four men brought the lower portion up over the upper parts. In a few moments, the concrete was made and set aside. Concrete made thus by men was as good as that made by machines, cost the same, and the fabrication took up little space.

The greatest attention was paid to the mortar being stiff, and to the stones used being clean and damp, for it was essential never to add water during concrete fabrication.

The finished concrete was placed in small boxes. A man put four on a wheelbarrow and transported them to a raft where the pouring was done. The small boxes were taken one by one, and the pouring was done gently into the large boxes that were to be used for casting.

It had first been thought to use a hopper, but firstly it would have had to be given colossal dimensions, as the excavation was 30.00 m wide; next, only 100 to 120 m^3 per day were poured. Now, for a hopper to function advantageously, it must be kept almost full. More than half the day would have been spent filling the hopper, and it could not have been left full at night, for the next day set concrete would have been found. It was therefore decided to use boxes. These boxes were triangular; they were suspended by two ropes unwinding from under a winch. After a certain time, two other slack ropes, attached to the lower edge of the box, wound onto the winch. The box tipped over, and the concrete was gently placed. Unfortunately, these boxes were too small. They held scarcely $\frac{1}{7}$ of a cubic meter.

The great concrete layer of the floor, which was to be 3.00 m thick, was done in three stages. Each 1.00 m layer was itself divided into 6 layers of about 0.17 m each, which advanced in steps and parallelly.

All these operations relating to the fabrication and pouring of concrete were carried out with the greatest regularity and seemed to promise immediate success. The concrete was left for 6 months. At the end of this time, pumping was started with two 20-horsepower steam engines. The level could not be lowered below 2.50 m from sea level; there had been settlements of the castings. As at that time excavations were being made for the projected third dry dock, part of the spoil was dumped back into the dock under construction, and a cofferdam of flowing ground(*) was made, which roughly isolated the fifth part of the dock. But for this cofferdam to be a perfectly watertight closure, it was necessary where it was formed to remove the inner cradle. To do this, it was sawn in sections by means of a circular saw run over the entire perimeter of the cradle. This part was successfully pumped out. The portion of

(*) The flowing ground is prepared for planting quite like ordinary earth, and if the weather remains suitable, nothing abnormal is observed in the way it behaves. But as soon as a little heavy rain comes, the entire loosened surface almost instantly dissolves and forms with the water a liquid mass, literally flowing over the area of the land. The water having then infiltrated the soil, a very hard crust remains on the surface, impermeable to the air and to the roots of the plants, and consequently extremely harmful to the vegetation. The flowing ground are found in more or less extensive patches in the fields; they occupy especially the slopes of the terrain. (Bulletin of the Belgian Geological, paleontological and Hydrological Society - 1887).
This is not in the original manuscript written in 42-43 but confirms the relevance of the process.

caisson remaining there was removed. The bottom was then seen to be pierced by a host of springs, almost all freshwater, coming from the mountain and having forced their way along each compression pile. Moreover, 2.00 m above the floor, a completely continuous sheet of water formed a cascade all around the foundation.

The bottom springs resulted from the concrete not having been poured in a sufficiently thick layer at once. Scarcely had the layer of about 0.17 m that was poured covered a spring, than this spring forced its way through and reappeared on the outer surface with the same intensity. When the second 0.17 m layer arrived, exactly the same thing happened; the spring forced its way through and thus reached the outer surface of the whole floor.

As for the great sheet surrounding the foundation, it came from the curved shape given to the caisson which had formed the inner wall of the enclosure. The concrete had not been deposited by the boxes in the place it was to occupy; it had been lowered vertically and left to take its slope under the kind of inclined shell of the caisson. Now it happened that the broken stone had taken a slope of about 45°, while the mortar had taken an inclination of 3, 4, and even 5 base to 1 height, so that at a certain height of the side wall was a portion containing almost only stones, through which water passed with the greatest ease. Above was a perfectly sound block.

A trench was first dug all around the floor, fairly deep, where the waters arriving on the floor collected. Then, on this floor, bricks of excellent quality were plastered with Pouilly cement, so as to form longitudinal rows leaving between them kinds of gutters in which the water flowed to the trench. On these bricks, another complete course of bricks was laid, so as to cover the small gutters. Two or three thicknesses of bricks were thus laid. The bricks and rubble to be used later were more or less uniformly distributed, and water was let back into the excavation, with the aim of exerting a pressure on the new constructions, a pressure that would cause them to undergo almost all the settlements they had to experience. After a fortnight, pumping was done. In some places, a few longitudinal cracks were found. All the bricks affected by these fissures were removed, replaced with others, always with Pouilly cement; two or three more courses of bricks were laid, water was put back, and so on. Finally, a brick floor 0.60 to 0.70 m thick was arrived at, which resisted water pressure perfectly.

This done, the side walls were raised. The bad parts of the concrete were first removed, and the new masonry adhered perfectly to the old using Pouilly cement. To prevent the water gushing from the side walls from washing away the fresh masonry being raised, it was directed by means of troughs suspended from ropes into the trenches where pumping was done.

The masonry of the side walls was not built solid. Square wells about 0.50 m were left all around, placed above the trench traced around the floor. When all the side walls were raised, water was allowed to rise in these wells, then on the same day, in all simultaneously, about 2.00 m height of mortar was first poured. This done, some large rounded blocks, roughly forming a piston, were thrown on top, which entered the mortar. Considerable pressure was

exerted on them so as to inject the mortar into the surrounding trench and into the gutters provided under the bricks. A portion even of the old concrete was injected. The wells were finished filling with concrete and other large blocks, which were tamped down as much as possible. When the wells were nearly full, a large stone was placed on top as a plug, on which, for a certain time, considerable weights were left so as to force the mortar to penetrate everywhere and stay there. This succeeded perfectly, and almost all the water disappeared.

A portion of the mud that had been brought to form the cofferdam was removed, and a second portion of the dock was built, then a third, and so on. Only, it would have been dangerous to immediately join a new zone to one that had already undergone all the settlements it was to undergo: infallible ruptures would have resulted. So a zone was raised without joining it to the old one except by small brick and Pouilly cement arches. The slightest difference in settlement in the two portions of the side wall was immediately absorbed by small movements in this arch. Sometimes six months were waited, and yet there were a few small leaks precisely at the junction of these two parts.

The whole dock was thus built up to the rabbets. There remained only four meters of mud cofferdam. To complete the side wall at the dock entrance, two mailleted wooden panels were placed on each side; between these panels and the old concrete, new concrete was poured.

Externally, two kinds of rustic masonry cones were arranged, formed of layers of concrete between which large blocks were intercalated.

There remain in the dry dock only small infiltrations, which are pumped out by a small 1-horsepower pump, running when the workshops are running.

It took eight years to build. It cost 1,300,000 francs plus 500,000 convict workdays, which evaluated at most at 1 franc bring the total expenditure to 1,800,000 francs.

Mr. Groignard had given the interior surface of his dry dock curved shapes similar to those of a ship. This arrangement forced the keel blocks or berths to always be established in the axis of the dock, so that every time they had to be arranged to receive a vessel, the dock had to be emptied, placed, filled a second time, and pumped out for the final repair. In Dock No. 2, the bottom of the dock was made flat. The keel blocks are then placed a little to one side of the axis, to the right for example, so that when the repair of a vessel is finished and it is to be replaced by another, the berths on which it is to be grounded are placed on the left. Water is let into the dock; the repaired vessel leaves, and the other enters immediately using the same water; one pumping is thus saved. The keel of ships is always curved. If, therefore, the keel blocks were placed so that their surfaces were flat, the ship would infallibly deform on them. So, before having it enter the dock, the plan of the keel must be very accurately surveyed, and the concavity it presents reproduced in relief.

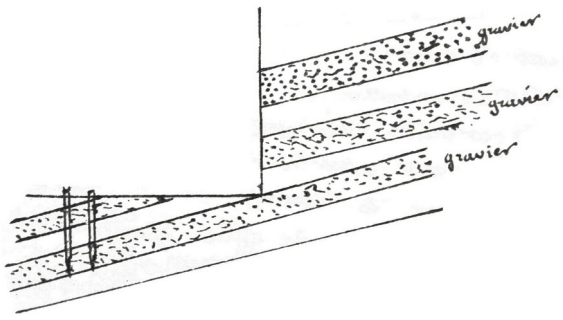
Dock No. 2 can receive large vessels. It has even received a 450-horsepower steamship, but instead of placing the door-boat in the groove that normally receives it, it was forced to put it in front of the rabbet that terminates the dock. As vessels of 600 horsepower will be built, they

will not be able to enter Dock No. 2, and as a third one is to be built, it will be given 15.00 m more length than Dock No. 2. As for the other dimensions, they will remain the same.

Construction of Dock No. 3. Should one return to the methods used by Mr. Groignard or continue the methods followed for Dock No. 2? Despite the accidents that occurred during the work, the latter ultimately cost more than half less. There is therefore reason to follow the same approach. By carefully studying the accidents, their causes can be partly covered, and consequently hope to avoid them in the new construction. They were due to three main things: the compressibility of the ground, the too small thickness of the floor layers, and the method used for pouring concrete.

The Groignard dock settled 0.10 to 0.12 m; Dock No. 2 settled 0.6 to 0.7 m. The piles therefore did not prevent settlement. For houses, for ordinary constructions, this Venetian method is very effective, but for constructions offering a flat interior surface 24.00 m wide by 100 m long, there will always be settlements. Then one must give up preventing them, for if a means were known to do so, it would have to be used, but as none is known, it is just as well not to pile, and as for the Groignard dock, settlements will reach 10, 12, even 15 centimeters perhaps, but in the first two docks, these settlements were not everywhere the same. Under the bricks, the saffre sank more than under the floor. Consequently, cracks and fissures appeared, and water entered from all sides. If, therefore, uniform settlement can be achieved, if at the same time as the side walls are raised the floor is loaded with rubble, with ballast, the whole construction will descend parallel and there will be no fissures.

By not piling, there will already be the saving of the cost of piles, but there will be another advantage: the saffre layers are inclined; the excavation will cut a certain number of these layers; others pass underneath without being touched, but if piles are driven, they are reached. Then all the waters flowing on these layers immediately rise along these piles, and they would never have come if an outlet had not thus been offered them. It can therefore be hoped to have fewer springs than in Dock No. 2. If some do come, a tarred canvas will be placed on the bottom to protect the concrete from their immediate action. It would be difficult to spread a canvas first over such a large area; waters arriving underneath could pierce it instead of fleeing over the whole length. This canvas, if used, will be placed on the raft used for pouring concrete. It will be unrolled and tarred as the pouring proceeds. This canvas will also facilitate the removal of laitance, which always flows at the foot of the slopes the concrete takes.



Whatever pouring method is adopted, masses of concrete as large as possible must be placed at once, and arranged so that one layer does not have time to solidify before receiving the next layer.

The floor will be 3.50 m thick; the pouring will be done in 7 layers of 0.50 m by means of seven boxes working in parallel. If larger boxes can be used to have only four layers, it will be done. The boxes open at the bottom as soon as they touch, and the mass is gently deposited. The concrete must have a consistency firm enough so that it does not flow too much; nevertheless, it will always take a certain slope, and it will not remain in the position where it was deposited; this would, however, be a very important thing to obtain. Perhaps oblique boxes could be made having approximately the inclination the concrete takes, and whose bottom and one of the sides would be closed by parts able to fold around each other, so that at the moment of placing the concrete, these 2 panels would be made to slide, which would easily bend, and the concrete would not move further. In localities where, like Toulon, there are great facilities for repair, one should not shy away from using somewhat complicated machines when great advantages are to result.

Whenever concrete is poured into water, a small portion of the lime is always removed and remains suspended in the liquid; then it deposits everywhere and forms a varnish which prevents the bonding of parts subsequently placed on the old ones. It is therefore necessary to get rid of it. For this, a constant current will be established in the dock by bringing in the waters from the pumping of the docks; 1 or 2 pumpings occur extremely often. In this way, the lime-laden water will be replaced by clear water. The removal of laitance will also be facilitated by moving bundles of old untwisted ropes through the water, on which the lime will deposit.

We have already spoken of the accidents caused by the curved shape given to the inner core, so the core of Dock No. 3 will be made vertical. The boxes forming this core will leave on each side, between their vertical walls and the rows of piles forming the enclosure, an interval of 5.00 m for the side wall concrete. This dimension will be too large for the upper part, and a portion will have to be removed for the masonry, but it would be dangerous to take a smaller one for the lower portions. The boxes will be 15.00 m wide and 20 m long. They will be placed one after the other; and when the concrete has been poured and has acquired suitable consistency, the last box will be lifted and placed outside the construction, and it will serve to support the cofferdam intended to close the foundation. As the side walls rise, the boxes will be uniformly loaded with ballast. At the same time, the necessary fills will also be made all around the foundation, but as it would be very difficult to do them simultaneously with the concrete, a vertical tarred canvas will be placed on the close-fitting piles to prevent the concrete from passing between the piles.

Each of the boxes can be pumped out separately. When the concrete has solidified, pumping will be started on the box farthest from the sea, the one closing the semicircle. The bottom of the box will be removed, and the condition of the floor will be examined. If it is sound, without too many springs, the second box will be pumped out. Its bottom will be removed, and so on for the whole construction at once. There would be an immense advantage in being able to raise

the masonry everywhere at once. The box walls will only be removed gradually and will serve as scaffolding.

The courses of dimension stone forming the interior facing of the dock will be of unequal height. The highest courses will be at the bottom and will decrease upward. This arrangement offers several advantages. First, it is very rare that a quarry offers beds of equal thickness; so, if uniform thickness is desired, certain beds must not be accepted and others must be thinned. There is therefore, in any case, a considerable loss, and consequently the stone is much more expensive. Next, suppose a stone receives a spall; in the case of uniform thickness, it is a lost stone, whereas by cutting it down, it can serve for a course of lesser height, and there will be only a small loss.

Moreover, this successive decrease in course heights produces a pleasing effect to the eye.

Closures of Dry Docks. At Brest and in some ocean ports, dry docks are closed by mitre gates. They have the advantage of being able to be operated fairly quickly, but saving time is much less important in a port where one is forced to wait for the tide to enter the dock. Mitre gates executed on such large dimensions hardly offer any solidity and require a considerable, and consequently very expensive, extension of the dock entrance.

Mr. Groignard had closed his dock with a door-boat having two keels fitting into grooves cut at the dock entrance. This vessel had no stability, and as soon as it ceased to bear in the grooves, it capsized on its side. To maneuver it, a beam with sheers had to be behind it to support it. This was a very cumbersome rig, which was nevertheless used for a very long time. Mr. Testel, naval construction engineer, had the idea of making a single leaf supported by lateral floats. By varying the position of the metacenter relative to that of the center of gravity, stability can be achieved, and the boat no longer capsizes as soon as it floats.

To maneuver the door-boat, it is brought over the grooves; two lower openings are opened. Water enters; the boat grounds by sliding between the grooves. It is secured by introducing wedges. To empty it, two pumps placed on the caisson itself are used.

Mr. Groignard feared that the boat might not bear well on the grooves and that when pumping began, an amount of air equal to that removed by the machines might arrive. He thought that if a level difference could be rapidly produced, the water being higher outside than inside, it would press the gate against the grooves, and pumping could then be easily completed.

To be able to produce an almost instantaneous level difference, he had a basin dug at the bottom of the dock after the semicircle, communicating with the dock by a valve. When the dock was to be emptied, communication between this basin and the dock was established. It filled in a few moments; the level dropped in the dock; pumping was then completed.

But all this did not work well. The wall of the circular part of the dock had been left too thin. Cracks appeared, and the use of this second basin was abandoned. It is now filled.

The door-boats built for Docks 1 and 2 at Toulon have the disadvantage of being usable only on one side, so that if accidents occur on the outer side of the caisson, it is very difficult to repair them. The boat planned for Dock No. 3 will be able to resist in both directions, so that if one side suffers damage, it can be placed on the inner side of the dock and repaired dry.

To let water into the dry dock, Mr. Groignard had established channels inside the side walls, but they were difficult to construct and impaired the solidity of the system. In Dock No. 2, it was preferred to put sluices on the door-boat itself. It would not be prudent to allow a considerable mass of water animated by great speed to fall onto the masonry. The joints would not resist and would soon be damaged. The water is brought into large wooden boxes, and from there it falls gently into the dock.

Hauling-up Slipway. The first two lessons of the course were devoted to the description and construction of these establishments of great interest, of which there are as yet only a few executed.

Grounding Slips and Careening Grids.

Grounding slips can only be advantageously used for vessels of any importance in ports where, as at Granville and St Malo, the differences between high tides are very great. At the highest tides, the vessel to be repaired is brought onto the grounding slip. The following high tides no longer reach the level they had attained, and the vessel remains dry. The first high tide that returns refloats it. Thus, this arrangement can only be used for repairs of short duration.

Sometimes, grounding slips, instead of being established in a cove that the sea only reaches at high tides, are formed by a grillage placed on piles in a corner of the port. They then take the name of *careening grids*. In some localities, openwork timber side walls have been placed laterally to be able to support props.

Hydrostatic Dock. This is the name given to a poor machine used in America for repairing ships. Between two quays is a platform that can be lowered a few meters below water. This platform is supported on each side by chains winding on 2 masts placed along the quay. The vessel to be repaired is brought onto the platform; the masts carrying the chains are turned by means of a hydraulic press driven by a 6-horsepower steam engine. The vessel comes out of the water and repair is done. Sometimes, each chain is acted upon separately by means of small hydraulic presses with screw jacks worked by men. Everything defective in such an arrangement can be seen. The rupture of a few pieces would suffice to cause the fall of the ship with the platform and the workers. And moreover, the whole vessel has to be lifted, which is a considerable weight, whereas with slipways, only ⅙ of the total weight is involved, and even if all the chains broke, the only drawback for the vessel would be to remain in place.

Various Establishments of a Port.

In a military port, there is a great quantity of establishments which are the indispensable accessories of all the constructions we have just spoken of.

They can be separated into three distinct classes.

1° Establishments for the receipt and preservation of raw materials.

2° Workshops for the use of these materials, to which must be added the stores intended for the preservation of finished articles.

3° Accommodation for men, barracks, prisons, convict prisons.

We will say a few words about each of these three main categories.

1° *Receipt and Storage*. Of all materials, the most important and that of which the most considerable supplies are held is timber. In a military port, there is 6 to 10 million francs' worth, and it could be lost in a very short time if poor quality had been accepted or if it were not known how to preserve it.

Defects in timber are of two kinds: structural defects and alterations.

Structural defects are shakes, frost cracks, and heart shakes (roulure, la gélivure, la cadranure).

Shakes are those where there is separation of concentric layers. Sometimes this separation occurs after very severe cold; in any case, the piece is singularly altered. The fibers being no longer bound, it no longer resists as a single piece. The fibers can slide relative to each other.

Frost cracks are splits in the direction of the radius. When timber is both shaken and cracked, the section presents the appearance of a dial, and workmen have named the combination of these two defects *cadramire* (heart shake).

It is very rare for timber not to be more or less split. Whenever the split is wide, continuous, penetrating to the center, the timber must be rejected.

The fibers of wood sometimes twist in a helix of more or less elongated pitch. The wood is then said to be twisted. When it is to be used for piles, large beams, etc., there is not much drawback. But if it is to be sawn into planks, the fibers would be cut short and would have no resistance.

There are also three main kinds of alterations in timber.

1° *Surface rot*. This disease, called *grisette*, is due to the fermentation of the sap. It is a contagious rot that follows the fibers longitudinally and spreads with great rapidity, especially from top to bottom, in the direction of the fibers. Grisette is much less dangerous when it attacks the base of trees. When timber is attacked by it, the fibers successively become black, grey, yellowish, finally white. A certain sign of this disease is

a strong odor of Spanish tobacco. Sometimes the fibers are covered with small holes. The timber is then said *to have gooseflesh*.

2° Knots are often the seat of another timber disease, much less vigorous and less contagious than grisette. Whenever timber is received, it must be examined on all sides, and a blow with an adze given on each knot. Often a black point or *partridge eye* is seen; this is an indication of the existence of a small decomposed, whitish mass, with a very pronounced mushroom odor. Generally, it does not penetrate to a great depth and can be totally removed.

3° *Dry rot*. This is the most terrible alteration of timber. It occurs internally and there may often be no external indication; there may be only at the ends, often not even there: the wood appears perfectly sound. When the alteration occurs at the ends, it is recognized by the cinnamon color the section takes; moreover, the wood becomes extremely friable. It is especially in resinous woods that this alteration is frequent. They are said to heat up much more than non-resinous ones.

Pinholes. There exists, especially in southern ports, a small winged insect which deposits on the timber an egg from which hatches a small white worm (*Limexylon navale*) that eats the wood. These worms being very small, they would do little harm if, as a result of their accumulation, rot did not follow, rot which is indicated by a very acid odor. Fortunately, the presence of these worms can be avoided. The butterfly only deposits its eggs because it has the instinct that they will find food in the *mucilage* of the wood, and if the mucilage is removed only to a small depth, the butterflies no longer come. To remove the mucilage, it suffices to immerse the timber for 6 months. It would be bad to immerse it longer, for what happens to wood subjected to the action of steam would occur: all the mucilage would be removed, and the wood would become brittle. After six months, the timber is removed from the immersion pits and gently dried in the shade. For immersion, they are made into rafts and sunk by loading them with rubble or by mooring them with chains fixed to piles driven around the perimeter.

Timber sheds must be covered, ventilated, sheltered from violent winds and the sun. All pieces of the same scantling should be put together, in the same bay. It would be useful, but this arrangement has not yet been executed in France, to establish on the main nave a carriage on which another smaller carriage could enter the side naves, so that a piece of timber could thus be lifted at any point and deposited on the cart or truck that would enter the shed.

In several ocean ports, timber is kept in muddy water. The mud prevents the action of water we spoke of earlier. The mucilage is only removed to a shallow depth. If seawater were used, the timber would be eaten by shipworms. Using fresh water, there would be other worms. A mixture of fresh and salt water is made, and no species of worm lives there.

Resinous timbers used for masting keep very well in water without mud.

Stores for substances other than timber present nothing special. Mr. Rubell has given the design of most of the stores built in the various ports.

2° *Workshops*. Almost all workshops present special requirements that must be considered in their construction.

Carpenters' and joiners' workshops are placed in open spaces reserved along the building slipways.

The most important workshops are the iron workshops where steam engines are built and repaired. Iron workshops present 5 main divisions.

1° *Large, medium, small forges for nail making*. Small forges are placed in workshops 15 to 20 m wide, lit from both sides along their length. Between each opening, there are two adjacent hearths. Thus, for each center distance, there are 4 hearths. Bellows are no longer used; a centrifugal fan is employed. This fan, driven by a 2 to 3 horsepower machine, can supply 75 small forges. The longitudinal duct bringing air into the whole workshop must be very wide. It is simply made of wood covered with clay. It must not be less than 0.35 to 0.40 m on a side. In front of each hearth, there is a red copper pipe, fitted with a tap by which air is brought to the fire.

   In forges intended for large pieces, it is appropriate to place the hammers in the middle of the workshop with a forge and a crane on each side to bring the pieces to be joined under the hammer.

2° *Foundries*. The furnaces most used currently are shaft furnaces or Wilkinson furnaces; the quantity of material and fuel is better regulated. Above these furnaces, there must be wide chimneys. Considerable supplies of coke must be kept near the furnaces. Coke ovens should be used for drying molds. It is useful to let the coal flame pass over these molds; a layer of soot deposits which greatly facilitates the casting.

   Large pieces must be cast vertically. Pits are then made near the furnaces with cranes to lower the molds into them and to remove the cast pieces. Moreover, in a foundry workshop, all cranes should correspond with each other.

3° *Fettling*. This is the first operation after casting.

4° *Fitting*. Fitting shops contain boring, turning, drilling, planing machines, etc.

5° *Erecting*. Erecting shops must have trolleys fitted with sheers running either on the floor or on the walls. Small pieces are lifted by tackles attached to the framework.

To all these workshops must be added a *boiler shop* for the manufacture of boilers. Boiler shops are simple sheds which should be as isolated as possible because of the considerable noise resulting from riveting.

Ropery. The raw material is always hemp. A rope is always composed of three elements. The first element, as in all ropes, is the *strand yarn*. It is a thread 2 to 3 mm in diameter, spun

in a straight line without winding onto a wheel. As ropes are 200 m long, the strand yarn is given 300 m. All the elements composing the strand yarn must be twisted in a helix, very regularly, without leaving any isolated small masses of hemp.

If a tarred rope is to be made, it is the strand yarn that must be tarred, for it would be bad to tar the rope once finished. Tar reduces the strength of ropes by at least 20%. This action is due to the *pyroligneous acid* it contains, which attacks the hemp. But tar is *indispensable* for cables that are to be wetted. It is important to put as little as possible on the yarn. For this, tar is gently heated in a water bath, then the yarn is passed through it on a small pulley immersed in the liquid.

The 2nd element of all ropes is the strand. The strand is composed of a number of strand yarns in proportion to the thickness desired. Formerly, strand yarns of equal length were taken, tightened at both ends, and twisted. It then happened that all the yarns were unequally tensioned. The yarns on the surface were the most tensioned. Tension decreased, became zero, then the threads were forced back on themselves down to the center thread. Cables thus made were very bad. When tension was applied to them, the surface yarns broke, then the next ones which in turn became the most tensioned, and so on down to the last. It is now possible to make strands composed of equally tensioned threads of unequal length. There is a metal plate pierced in its center. One strand yarn is passed through it. Around the first hole are arranged concentrically 7 holes of equal diameter. Around this first circle, another pierced with 14 holes, a third with 21, and so on in steps of 7. Strands of 8, 15, 22 threads can thus be made. Each of the threads, before being put into the plate, is placed on a wheel from which it can unwind freely. All the threads are gathered into a bundle and tightly gripped in a tube of suitable size. This tube is attached to a carriage having both a translational and a rotational movement. The thread unwinds freely, each the amount needed to undergo roughly uniform tension. To produce both translational and rotational movement at the same time, the rope moving the carriage passes over a vertical-axis pulley fixed on this carriage. On the axis of this pulley is a bevel wheel which turns the hook where the threads are made fast. Thus, full possibility is given to vary the pitch of the helices formed by the threads. Usually, 5 times the diameter is taken.

Once the strand is made, it cannot be left like that; it would infallibly untwist and have no solidity. Three strands are then taken, given a slight extra twist, and twisted in the opposite direction to the twist previously given to them. The three strands, tending to untwist, exert pressure against each other which prevents them from doing so, and an invariable system is obtained.

The assembly of three strands forms a *hawser*. Hemp cables of 4, 5 strands have been made, but four, five circles in contact can vary and change position relative to each other without ceasing to be tangent, and a hawser of four, five strands presents no solidity, unless a central core of another rope is put in the middle, but this rope is wasted and becomes a focus of rot.

When very strong ropes are wanted, a cable or hawser-laid rope is formed, made with three hawsers; as the hawser with three strands, the three hawsers are twisted in the opposite direction to the twist given to them in their individual manufacture. The pitch of the hawsers is three times the strand diameter.

It is advisable to have powerful means of ventilation in the workshops where hemp heckling is done, for it is better to use men than machines for this operation. Men do a little less work, but it is better done and there is less waste.

Rope works present spinning and laying workshops. Laying is the actual manufacture of cables. For this, workshops 300 m long are needed. Hemp has been successfully spun by winding it onto spinning wheels as it is made, but for laying proper, it is very difficult to ensure the equal tension of the strands before their use, and until now, in France, laying as we have described is preferred.

Accommodation for Men.

1° *Barracks*. It has now been recognized that it is better to lodge men by company than otherwise. It is therefore essential to have a large room divided into 4 or 8 bays separated by walls, or simply by pillars joined by a partition at chest height, in which 108 men can be put. A room for the four sergeants, a room for the sergeant-major are also needed. A large corridor should connect all the rooms. It is better placed in the middle of the building than on one of the façades.

It is very important to have, for each division corresponding to a company, a vestibule as large as possible. This vestibule communicates with the top of the building; all the bays communicate with this vestibule through openings placed as high as possible. Breathed gases always rise, and ventilation occurs without disturbing the men. Rooms should be 4.00 m high; each man should have 14 to 15 m^3 of air. In hospitals, 30 m^3 must be allowed. As far as possible, windows should not be placed against a bed, but between two rows; in this way, the men nearest the window are not inconvenienced by drafts. If possible, it is better for windows to start at the very floor of the room. Upward currents are produced which greatly stimulate ventilation.

Service buildings should not be given too much importance. Their area should be between $\frac{1}{3}$ and $\frac{1}{4}$ of the inhabited area.

Finally, the following results should not be deviated from: a barracks, including all service buildings, should never cost more than 500 francs per man, and even in many localities, expenditure can be limited to 400 francs per man.

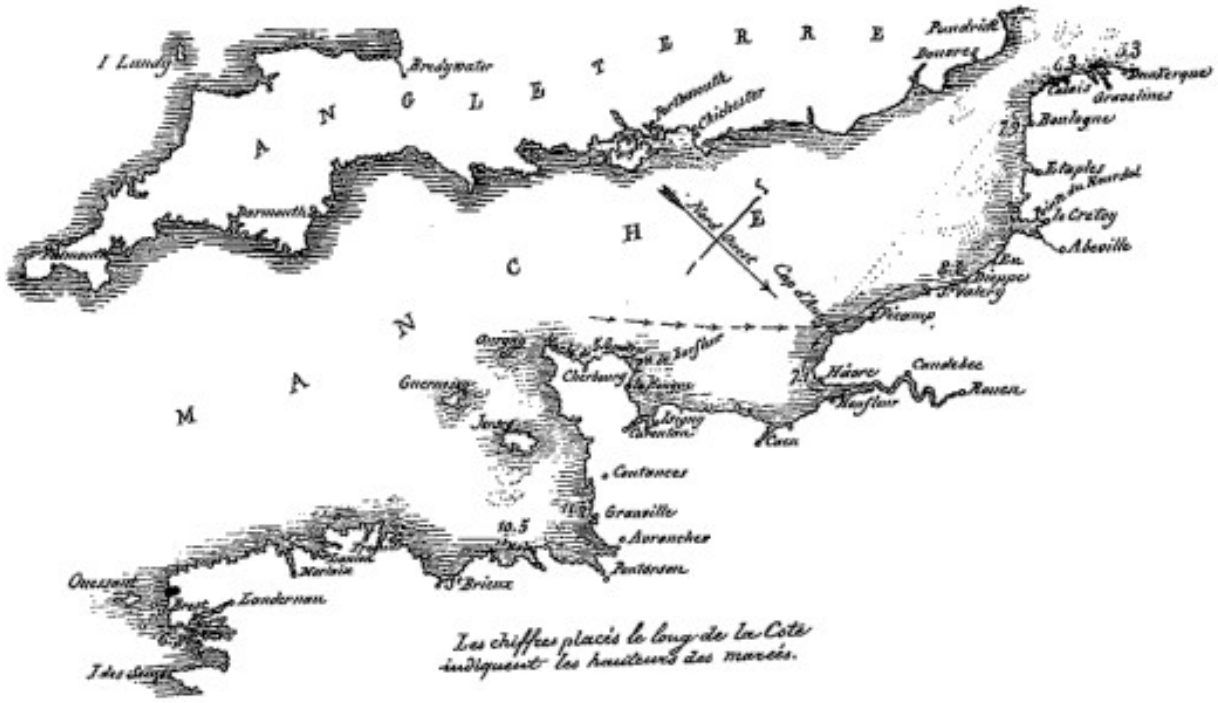
Convict Prisons (*Bagnes*). The current organization of convict prisons is detestable. Convicts in contact with free men do nothing and only serve to make the others bad. Next, they should be divided into three classes, divisions based not on the length of sentence, which

signifies nothing for classifying their morality. If there were a distinction to be made, it would be in favor of those sentenced to life or long terms, but the good, the bad, the doubtful must be separated; they must never leave the prison; workshops and dormitories must be combined in the same establishment; there must never be any contact with free men.

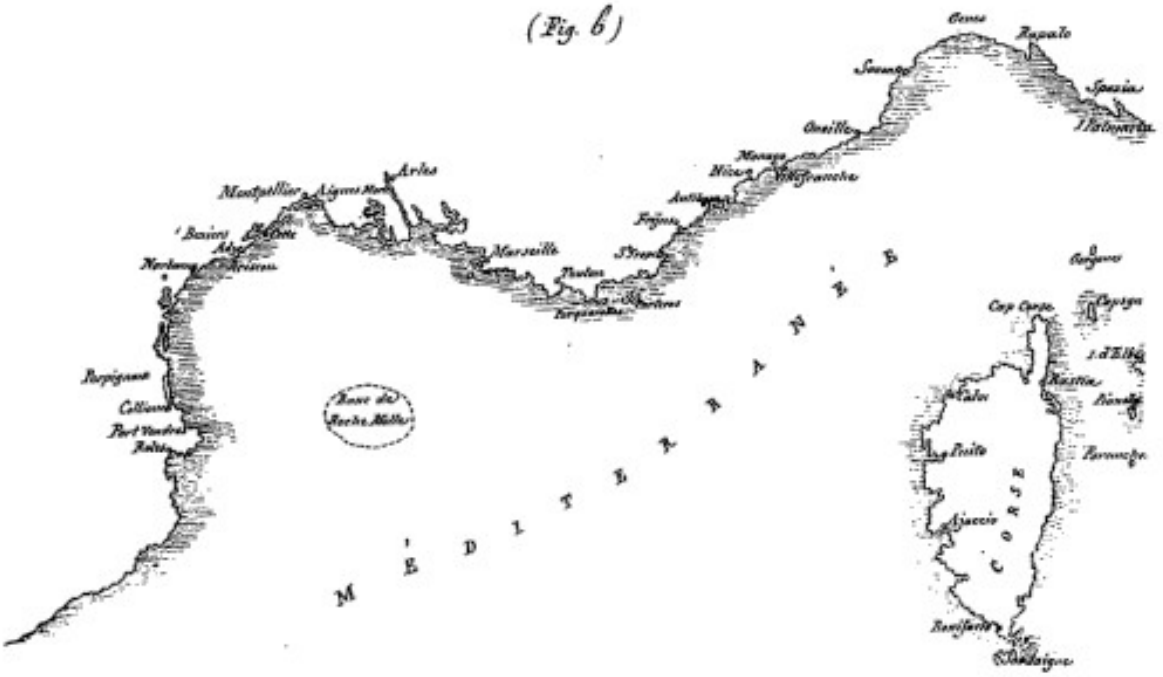
A convict prison should therefore be divided into three main divisions and each of them into two; the supervision and administration building should be in the middle; the whole surrounded by a large wall. Corridors should be placed along the dormitory where supervisors would constantly walk; finally, avoid gathering too many convicts in the same sleeping quarters. Thus, revolts will be less frequent and can be easily repelled.

(Fig. a.)

Pl. A.

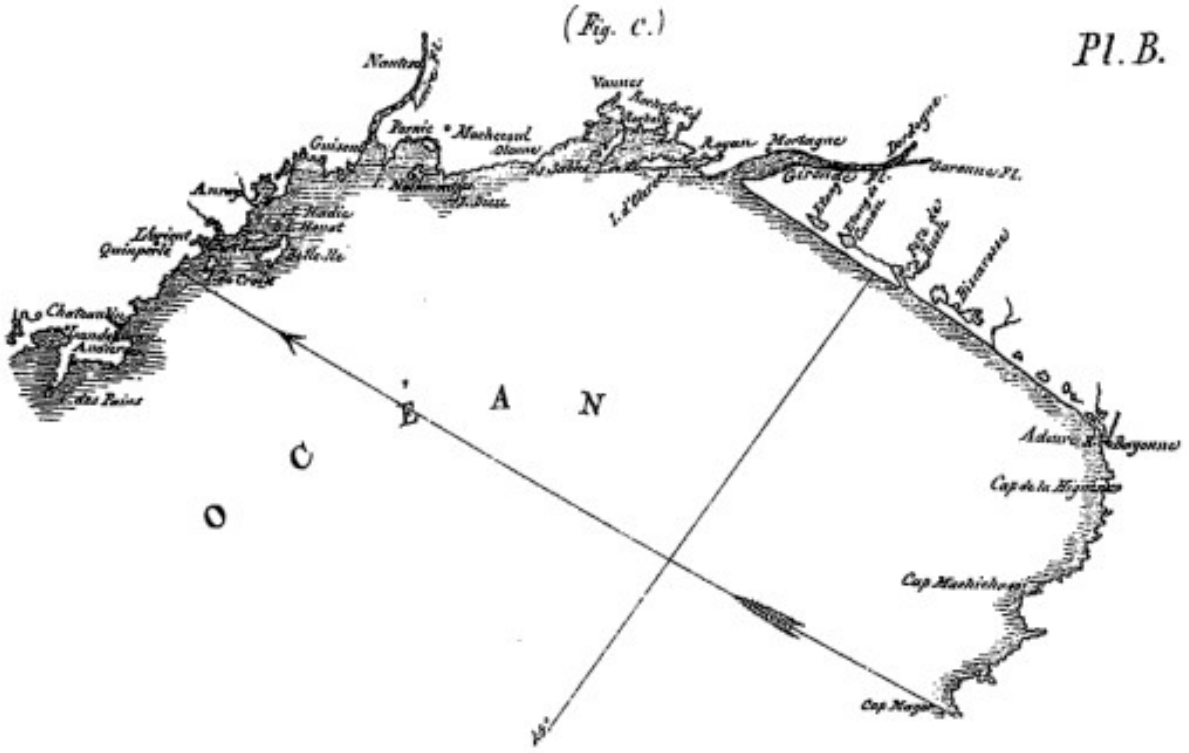


(Fig. b)

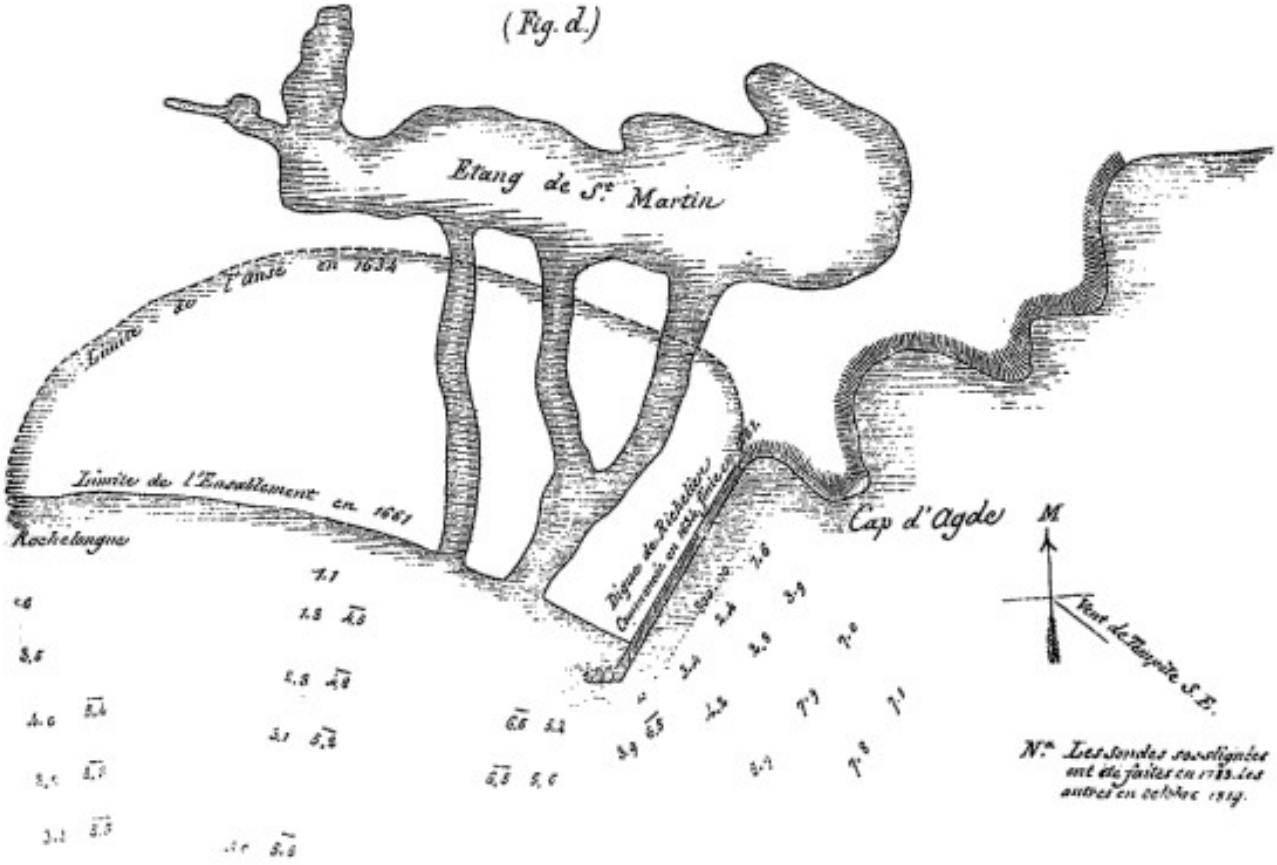


(Fig. c.)

Pl. B.

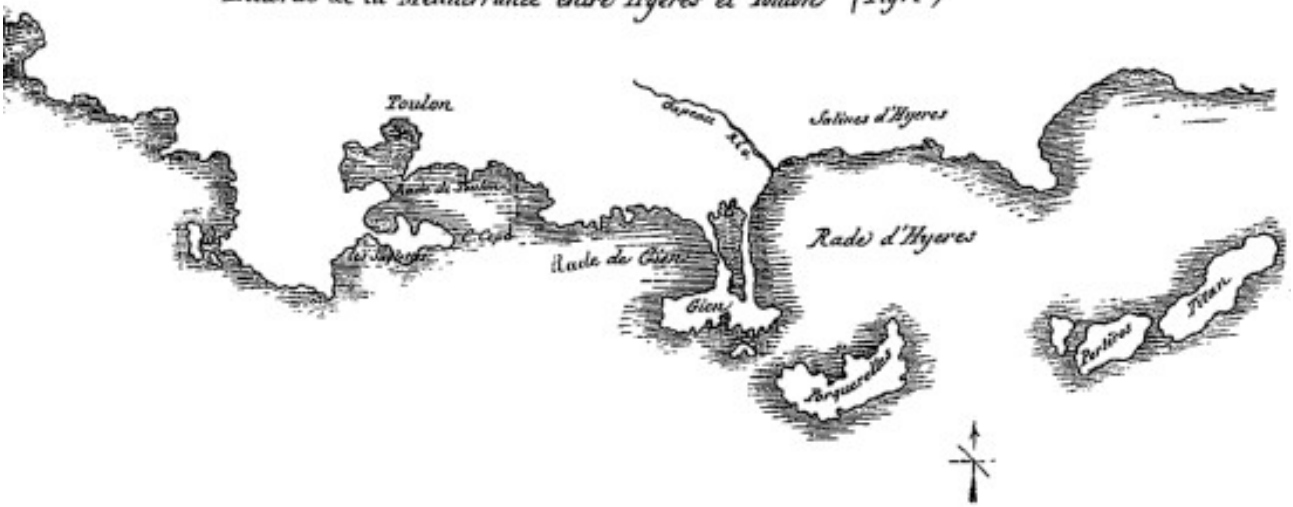


(Fig. d.)

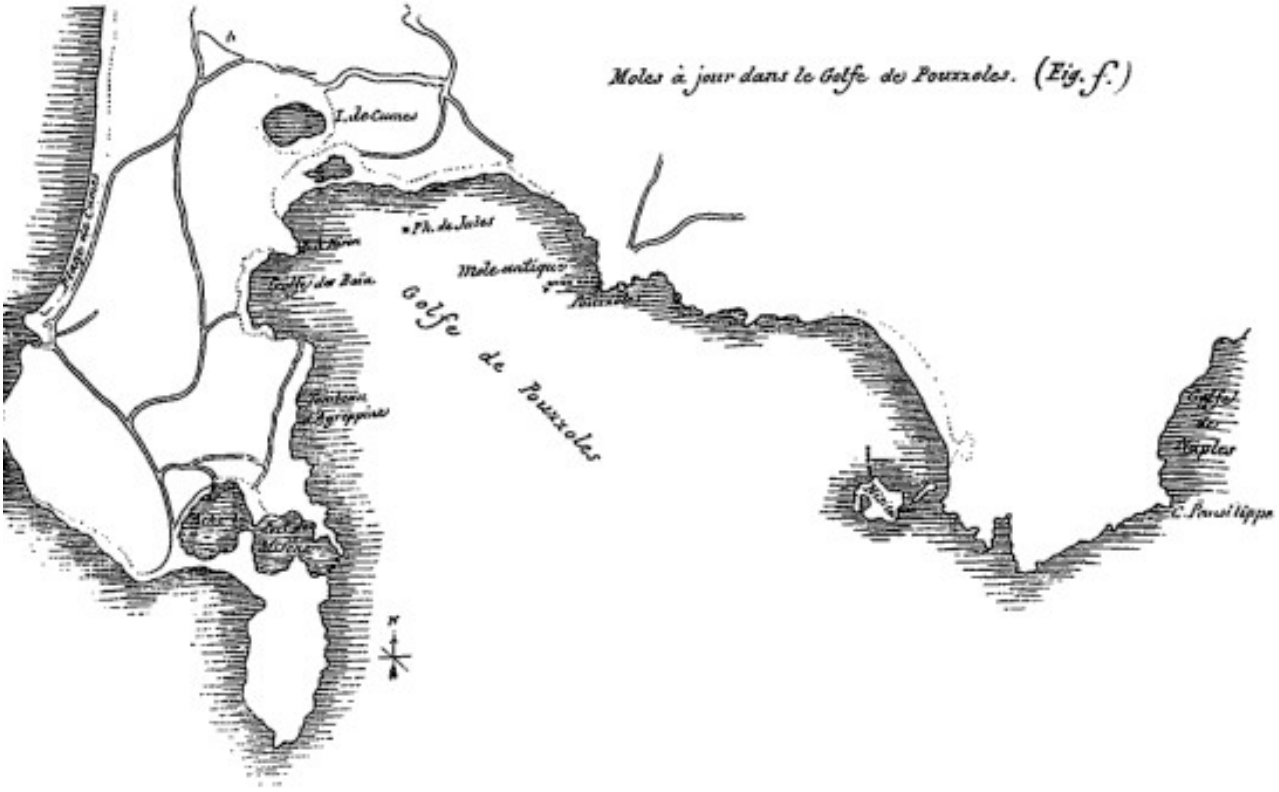


Pl. C.

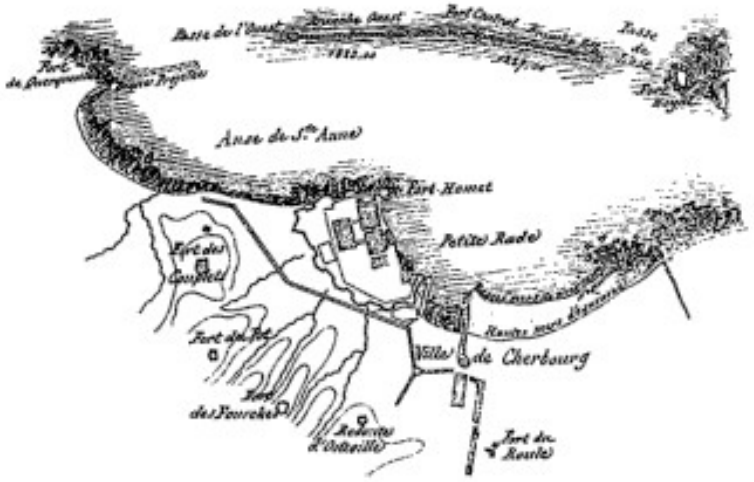
Littoral de la Méditerranée entre Hyères et Toulon (Fig. e)

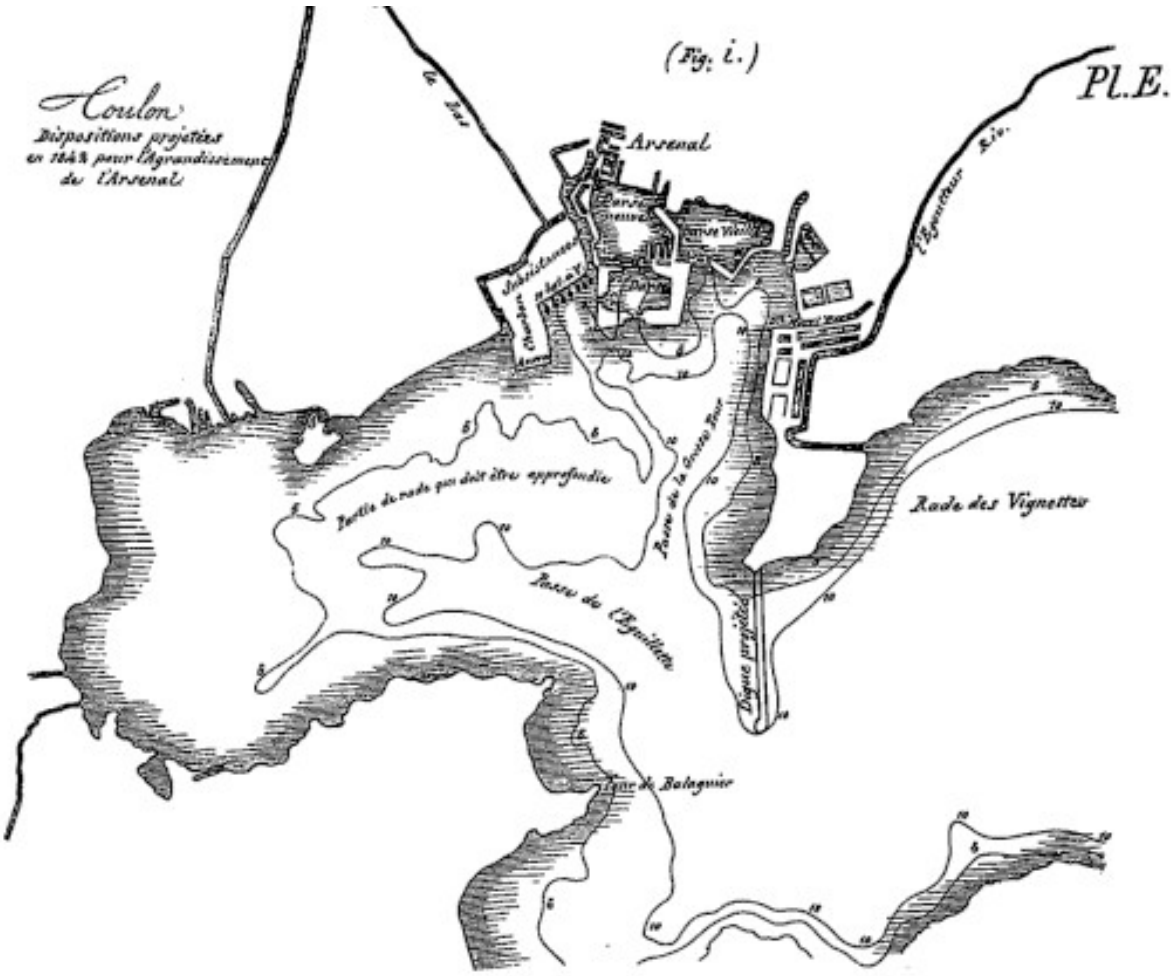


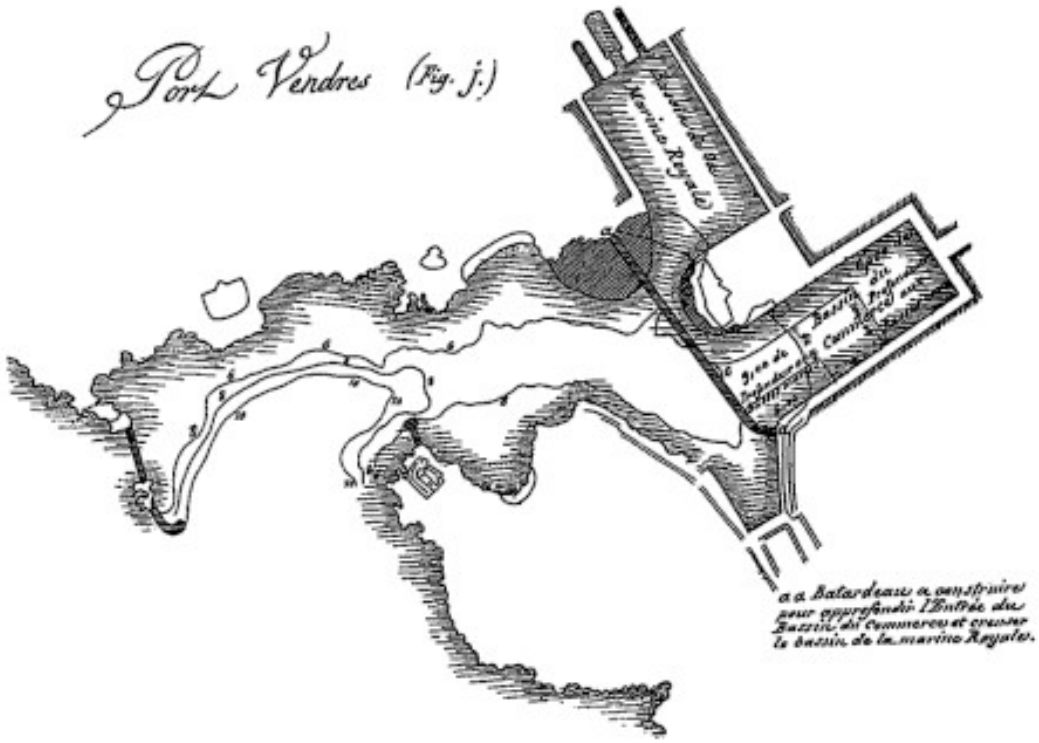
Moles à jour dans le Golfe de Pouzzoles. (Fig. f.)

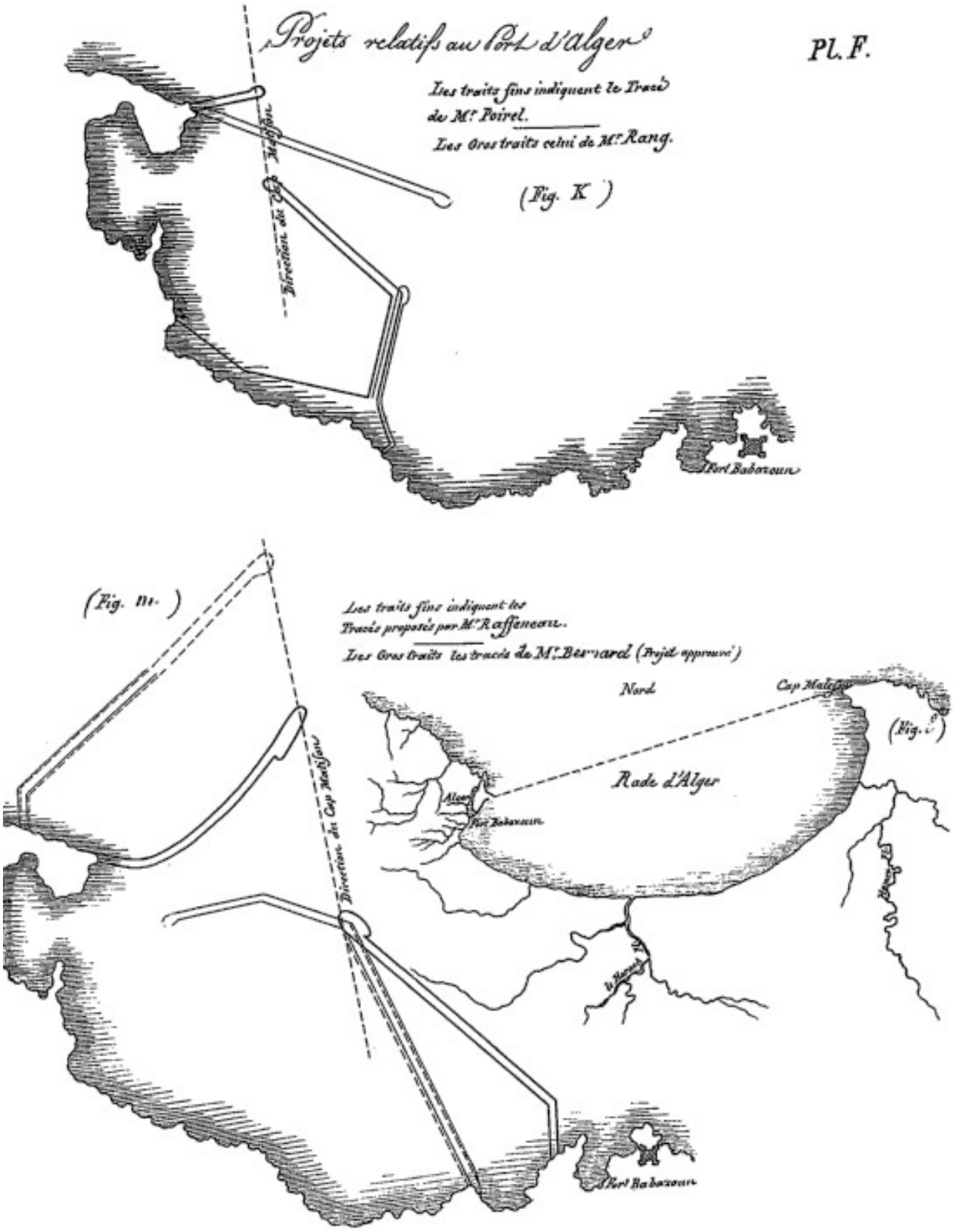


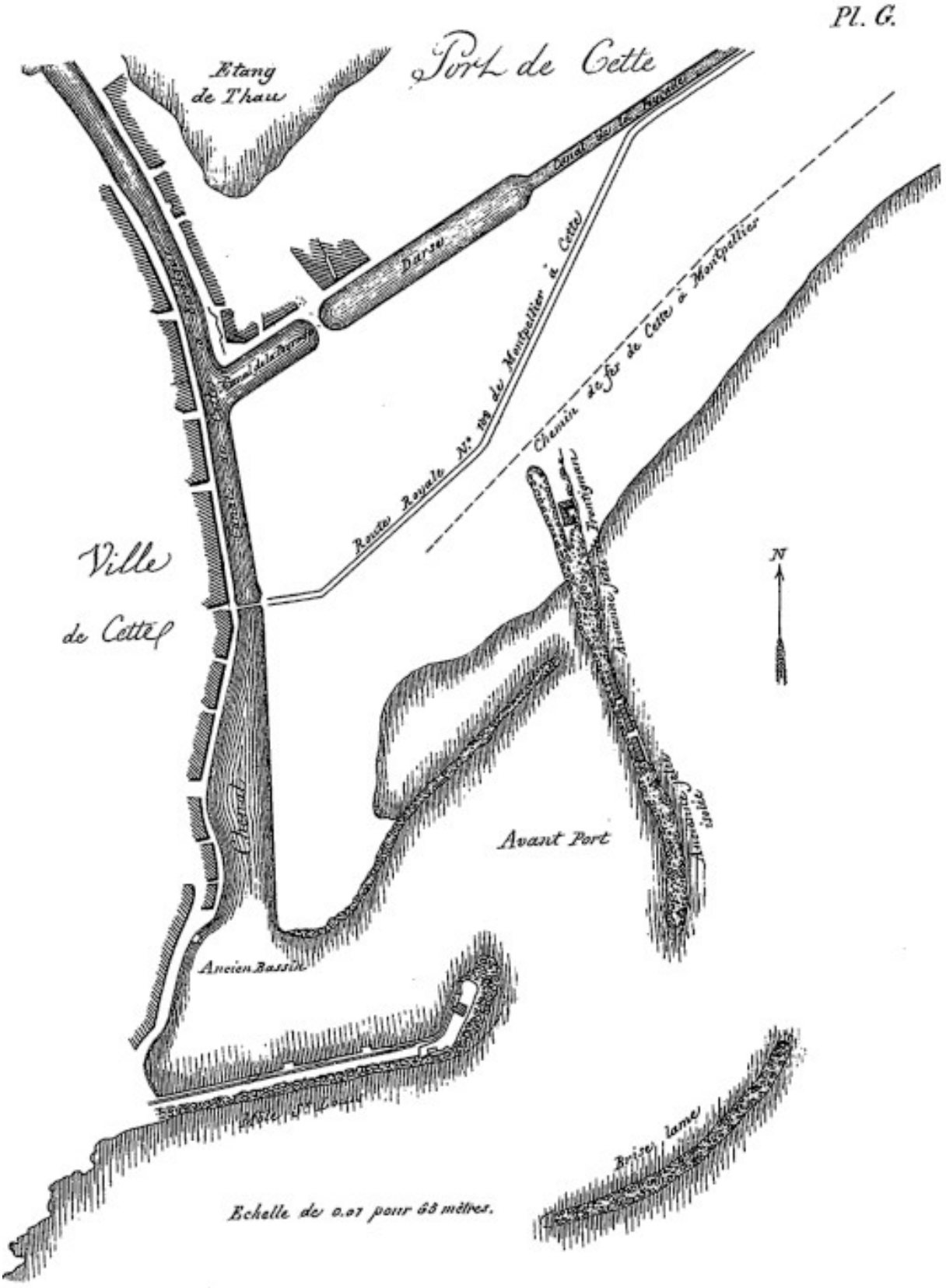
Port de Cherbourg (Fig. h.)

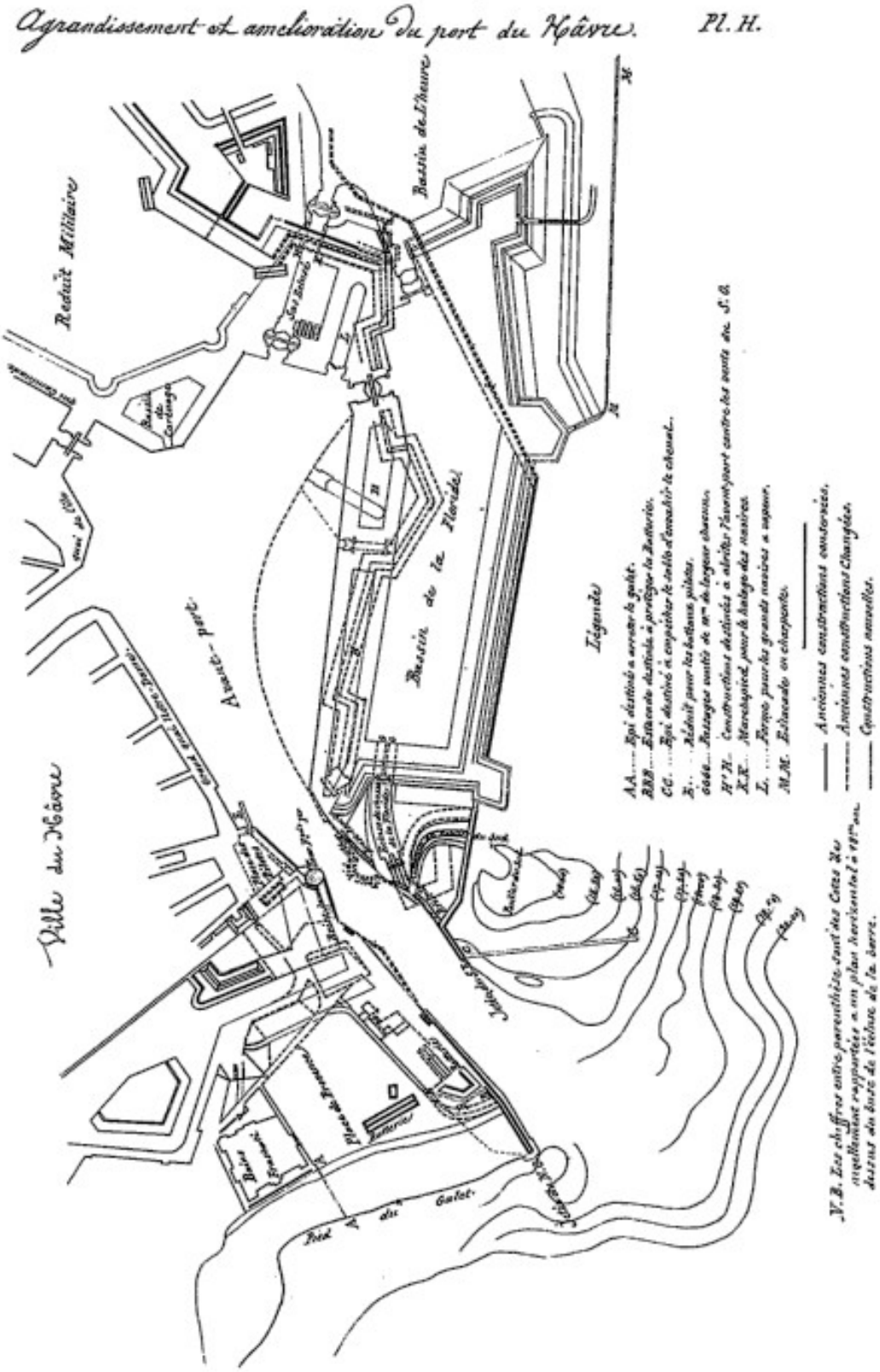


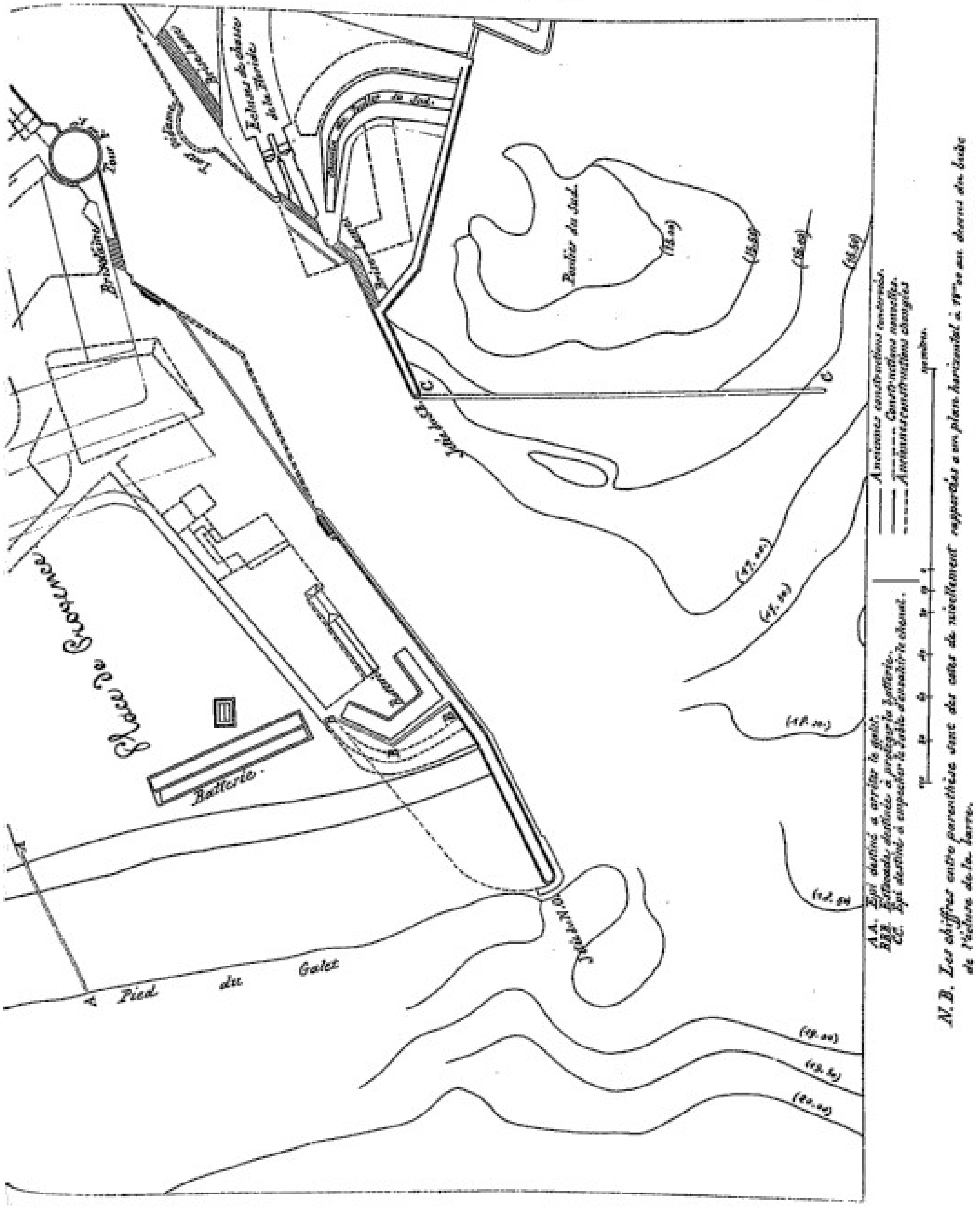

(Fig. i.)
Pl.E.
Toulon
Dispositions projetées
en 1842 pour l'Agrandissement
de l'Arsenal
Arsenal
Parse Vieille
Parse Neuve
Parse de la Grosse Tour
Partie de rade qui doit être approfondie
Passe de l'Eguillette
Rade des Vignettes
Digue projetée
Tour de Balaguier


Port Vendres (Fig. j.)
Marine Royale
a a Batardeau a construire
pour approfondir l'Entrée du
Bassin du Commerce et creuser
le bassin de la marine Royale.


Projets relatifs au Port d'Alger
Pl. F.
Les traits fins indiquent le Tracé de Mr Poirel.
Les Gros traits celui de Mr Rang.
(Fig. K)
Direction du Cap Matifou
Fort Babazoun
(Fig. m.)
Les traits fins indiquent les Tracés proposés par Mr Raffeneau.
Les Gros traits les tracés de Mr Bernard (Projet approuvé)
Nord
Cap Matifou
(Fig. l)
Rade d'Alger
Alger
Fort Babazoun
Direction du Cap Matifou
Fort Babazoun

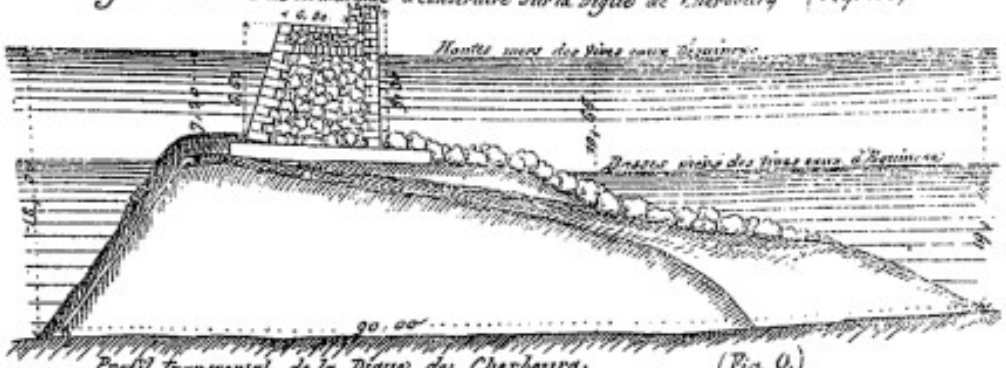

Pl. G.
Port de Cette
Etang de Thau
Darse
Route Royale N.o 113 de Montpellier à Cette
Chemin de fer de Cette à Montpellier
Ville de Cette
N
Avant Port
Ancien Bassin
Brise lame
Echelle de 0.01 pour 68 mètres.


Agrandissement et amelioration du port du Hâvre.
Pl. H.
Ville du Hâvre
Reduit Militaire
Bassin de l'heure
Bassin de la Floride
Avant-port
Légende
AA.... Epi destiné a arrêter le galet.
BBB.... Estacade destinée à protéger la Batterie.
CC.... Epi destiné à empêcher le sable d'envahir le chenal.
E.... Réduit pour les bateaux pilotes.
6666.... Passages voutés de 10m de largeur chacun.
H'H.... Constructions destinées à abriter l'avant-port contre les vents du S.O.
K.K.... Marchepied pour le halage des navires.
L.... Forme pour les grands navires a vapeur.
M.M. Estacade en charpente.
Anciennes constructions conservées.
Anciennes constructions Changées.
Constructions nouvelles.
V.B. Les chiffres entre parenthèse sont des Cotes de nivellement rapportées a un plan horizontal à 18m au dessus du buse de l'écluse de la barre.
Pied du Galet.

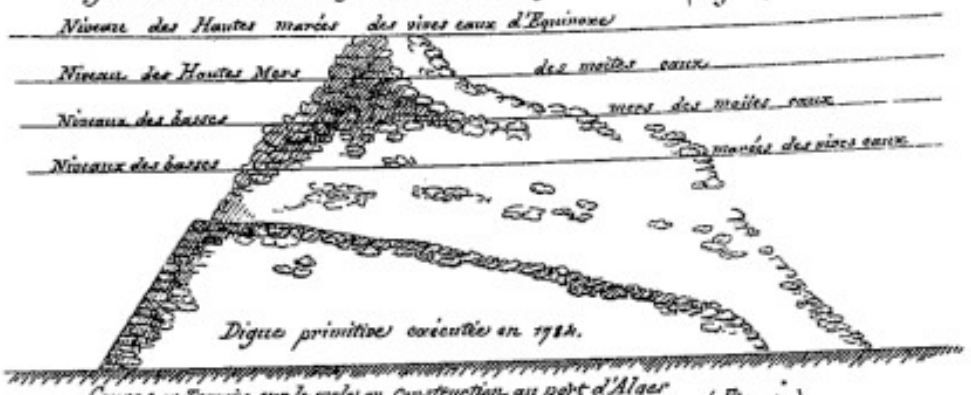

Place de Provence
Batterie
Pied du Galet
Banlieue du Sud
Tour
Brise-lame
(15.50)
(16.00)
(16.50)
(17.00)
(17.50)
(18.10)
(19.00)
(19.50)
(20.00)
A.A. Epi destiné à arrêter le galet.
BBB. Estacade destinée à protéger la batterie.
CC. Epi destiné à empêcher le talus d'envahir le chenal.
Anciennes constructions conservées.
Constructions nouvelles.
Anciennes constructions changées
N.B. Les chiffres entre parenthèse sont des cotes de nivellement rapportées à un plan horizontal

Profil transversal de la muraille à Construire sur la Digue de Cherbourg (Fig. n.)

PL. I



Profil transversal de la Digue de Cherbourg. (Fig. o.)



Coupes en Travers sur le mole en Construction au port d'Alger (Fig. p.)

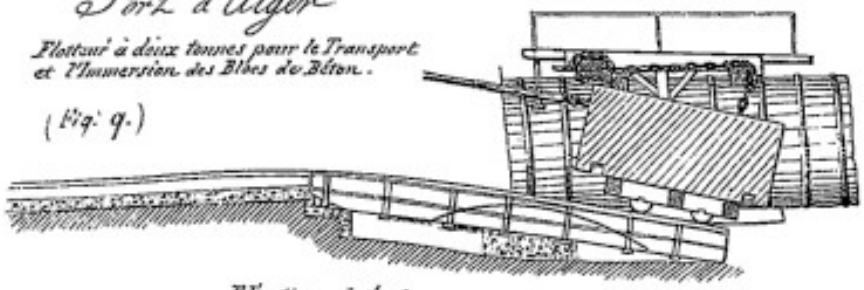
Avant la tempête du 21, 22, et 23 janvier 1841.

Coupe en long

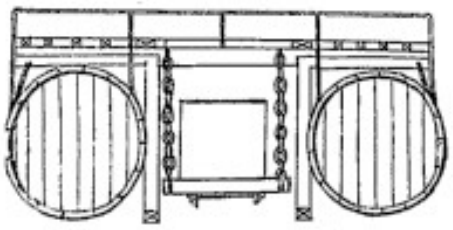
Port d'Alger

Flotteur à deux tonnes pour le Transport et l'Immersion des Blocs de Béton.

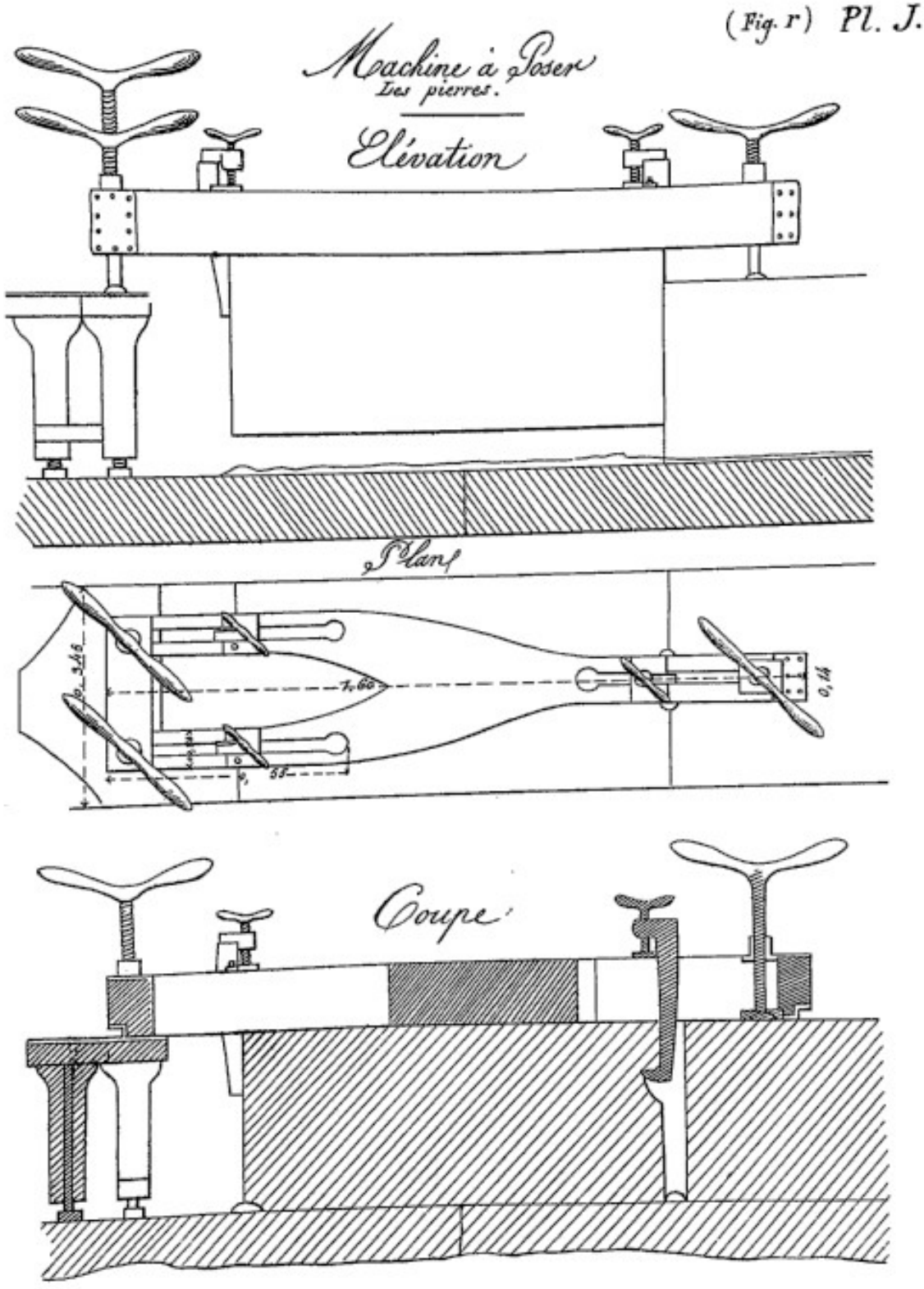
(Fig. q.)



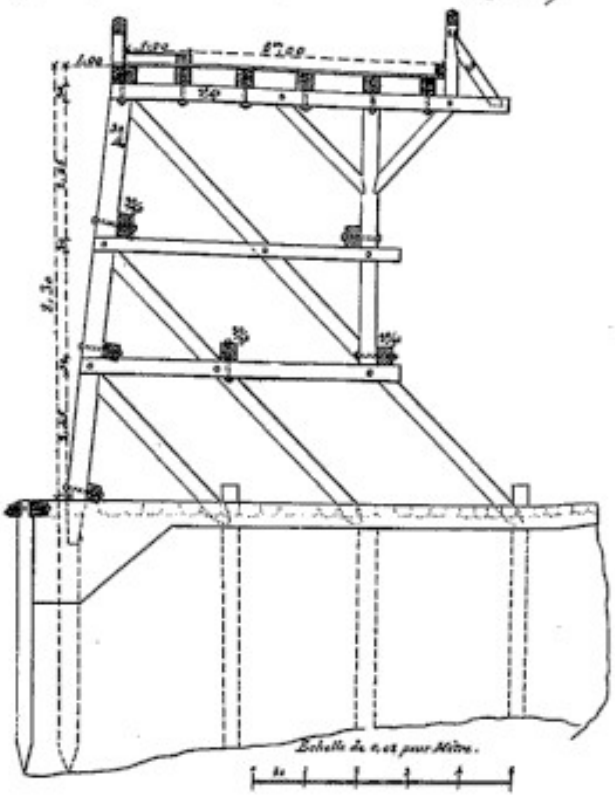
Élévation latérale



(Fig. r) Pl. J.



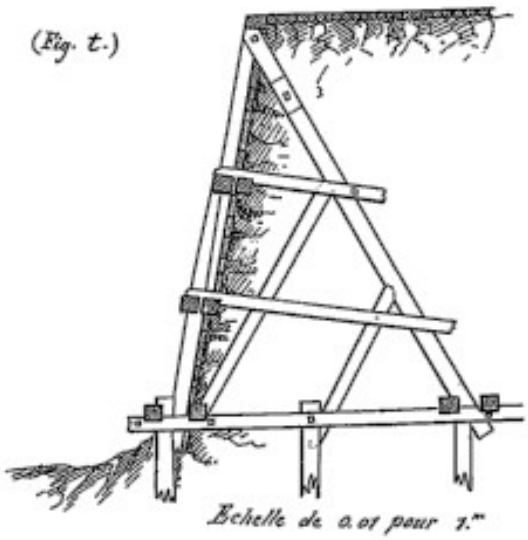
Projet de Claire-voie pour la porte du Hâvre (Fig. S.)



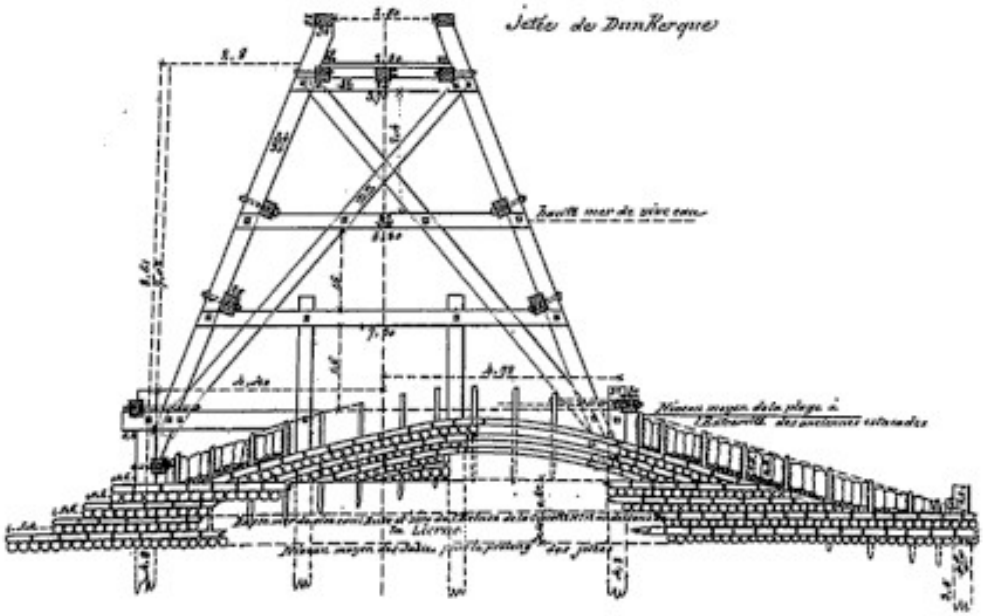
Pl. K.

Coupe Verticale d'un quai en bois.

(Fig. t.)



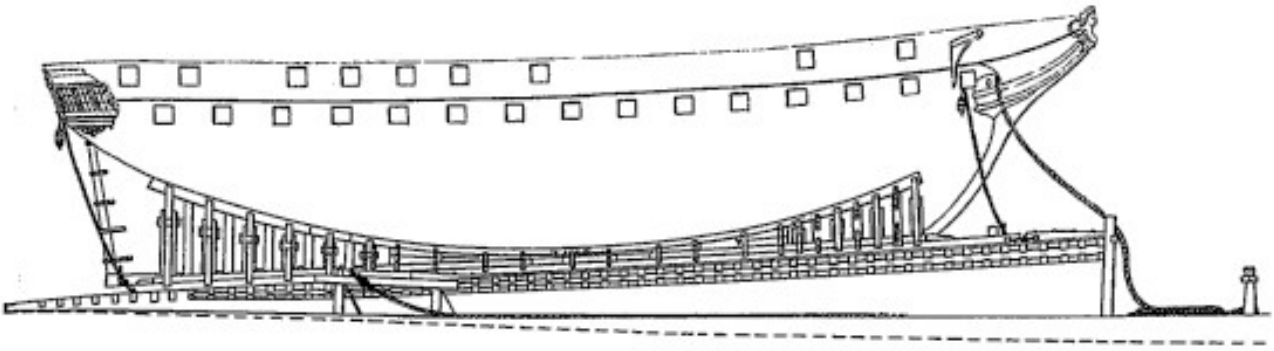
(Fig. u.)



Berceau de Lancement
Pour les Grands Bâtimens.

Pl. 1.e

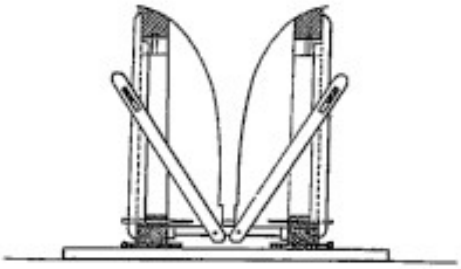
(Fig. 1.)

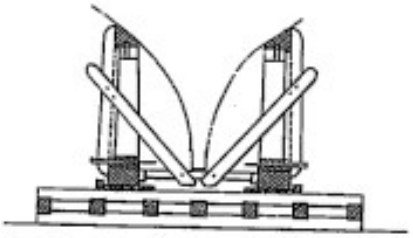


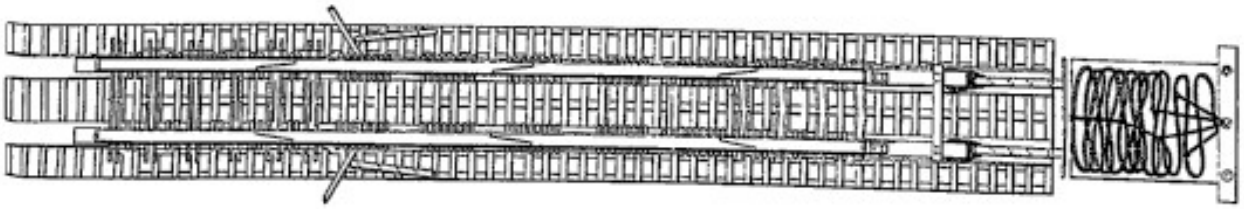
Coupe au dernier Colombier (arrière)
(Echelle triple de celle du plan.)

Coupe au premier Colombier (avant)
(Echelle triple de celle du Plan.)

(Fig. 2.)



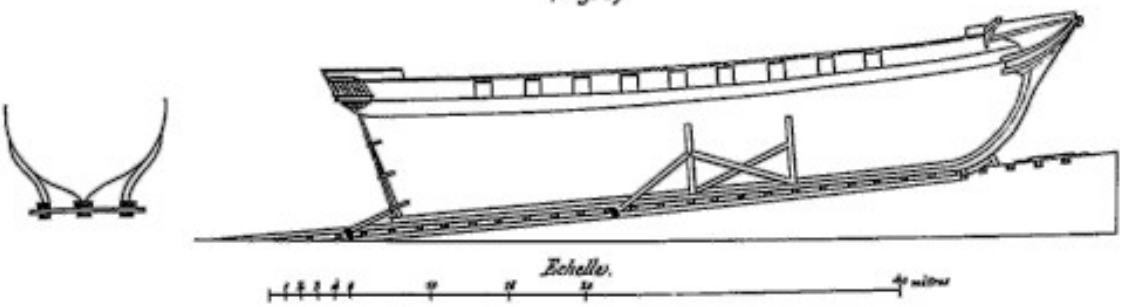




Echelle de 0,008 p.r 1 mètre

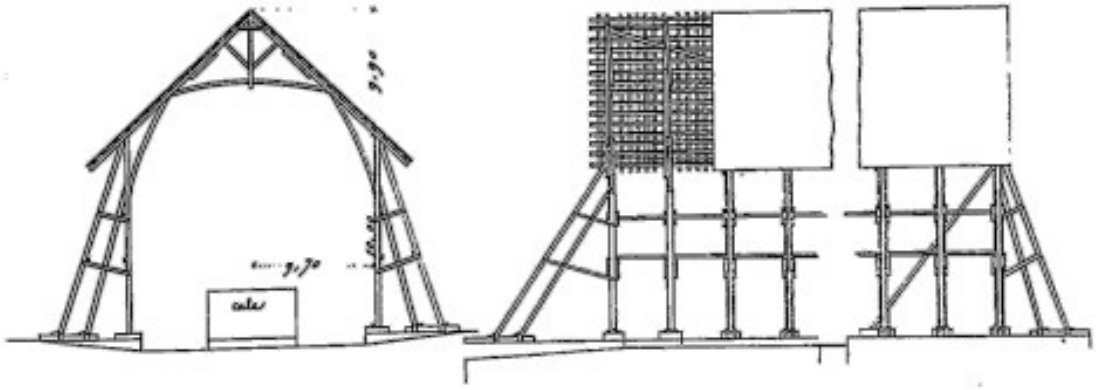
Appareil dit à Béquilles, pour la mise à l'eau des bâtimens du 2.e rang.

(Fig. 3)



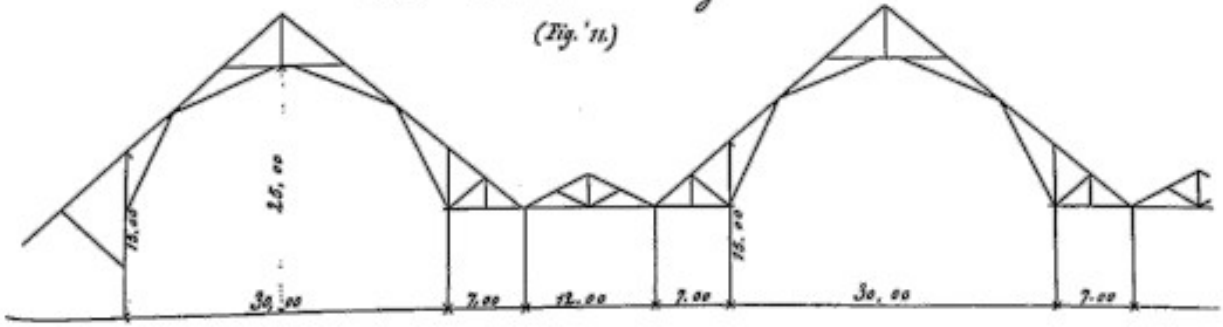
Cales couvertes de Rochefort.

(Fig. 10)

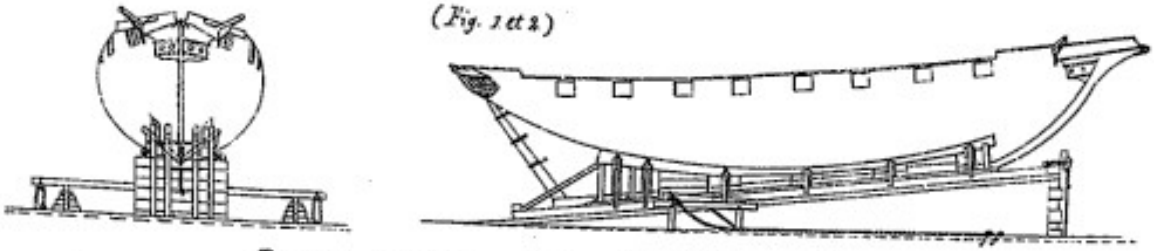


Cales couvertes d'Angleterre.

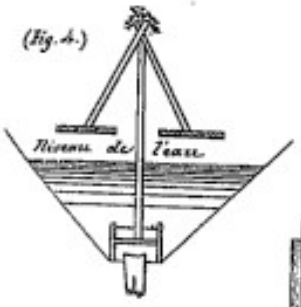
(Fig. 11)

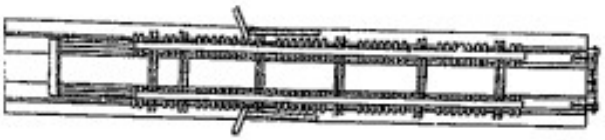


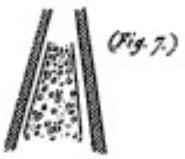
Pl. 3.e

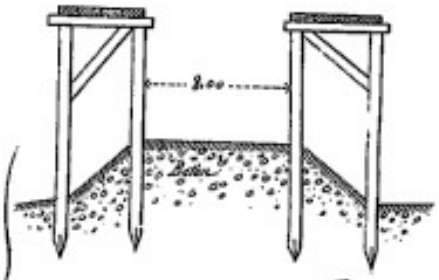


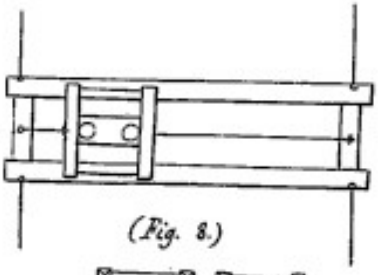
Berceau de lancement pour les Batiments légers

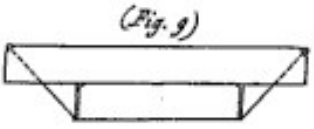


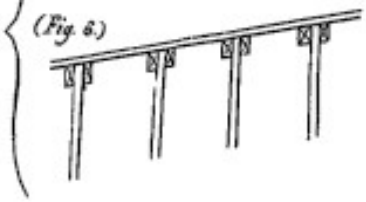


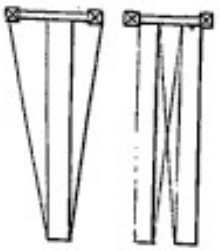


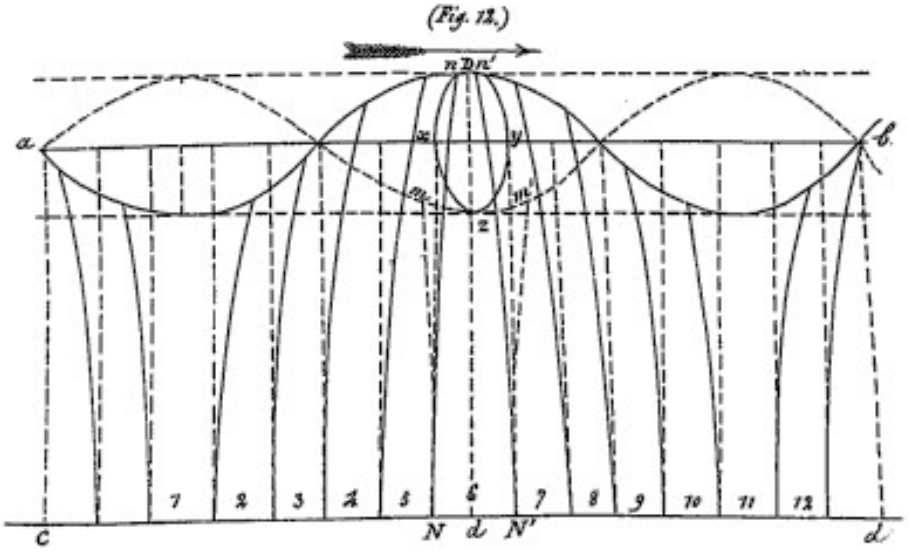


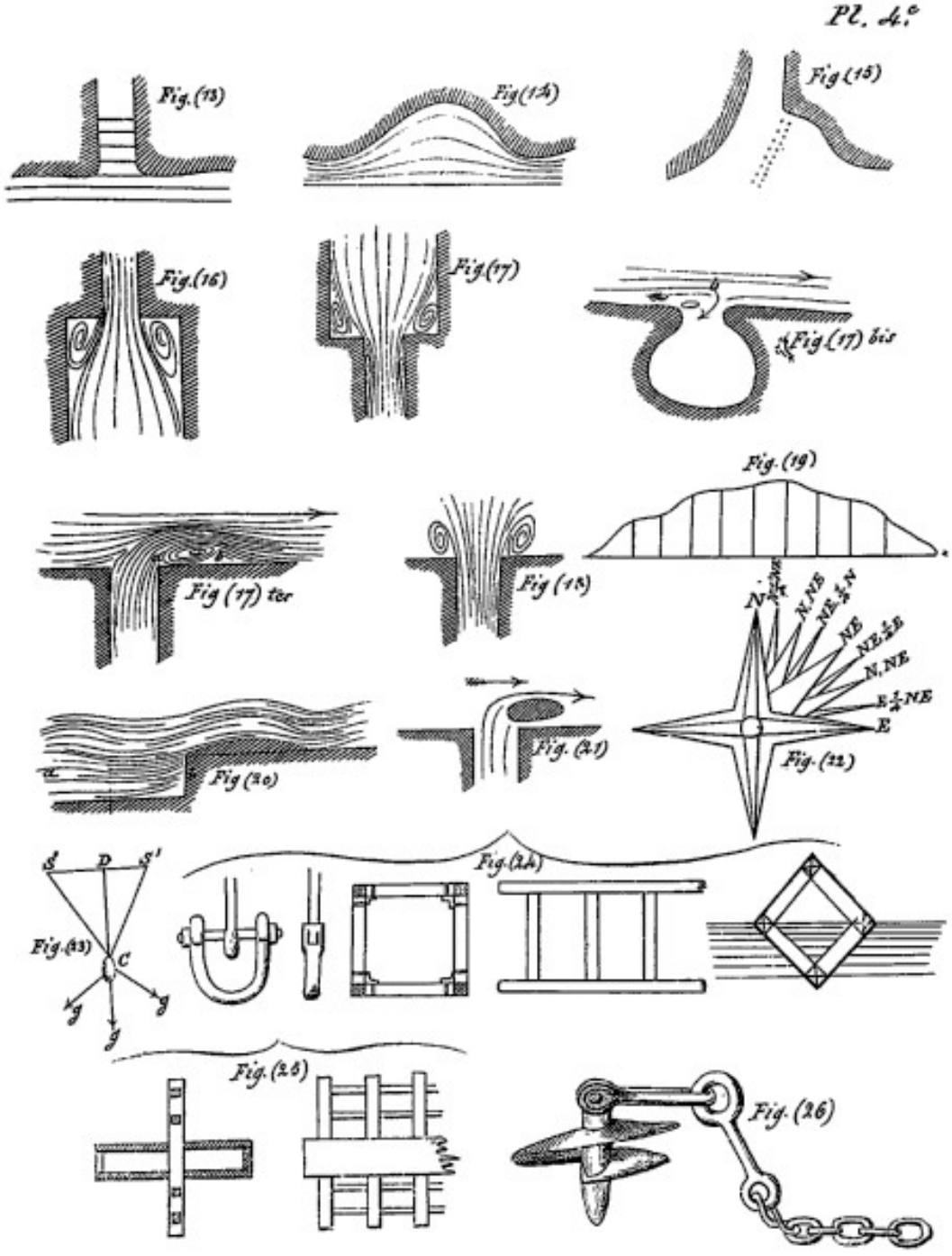






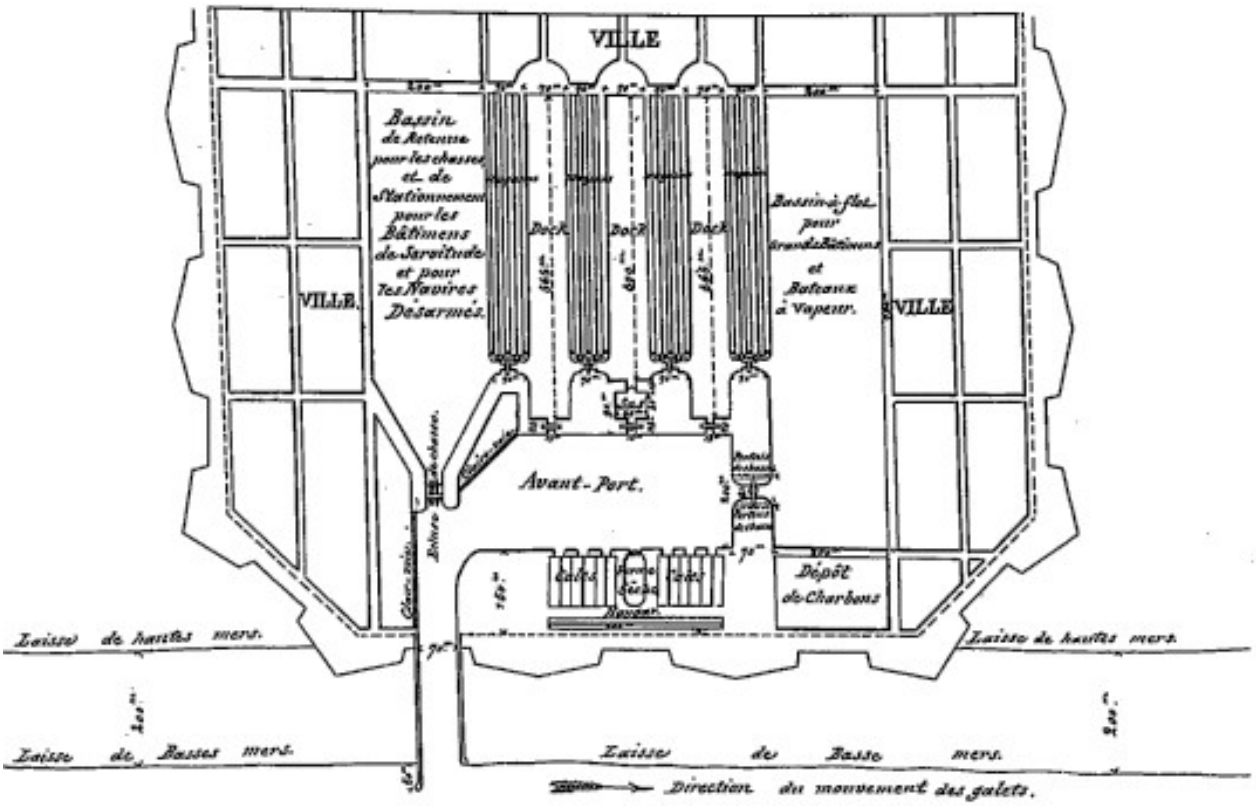





Pl. 4.e
Fig. (13)
Fig (14)
Fig (15)
Fig. (16)
Fig (17)
Fig (17) bis
Fig. (19)
Fig (17) ter
Fig (18)
N
N.NE
NE
N.NE
E
Fig. (20)
Fig. (21)
Fig. (22)
S
D
S'
Fig. (23)
C
g
Fig. (24)
Fig. (25)
Fig. (26)

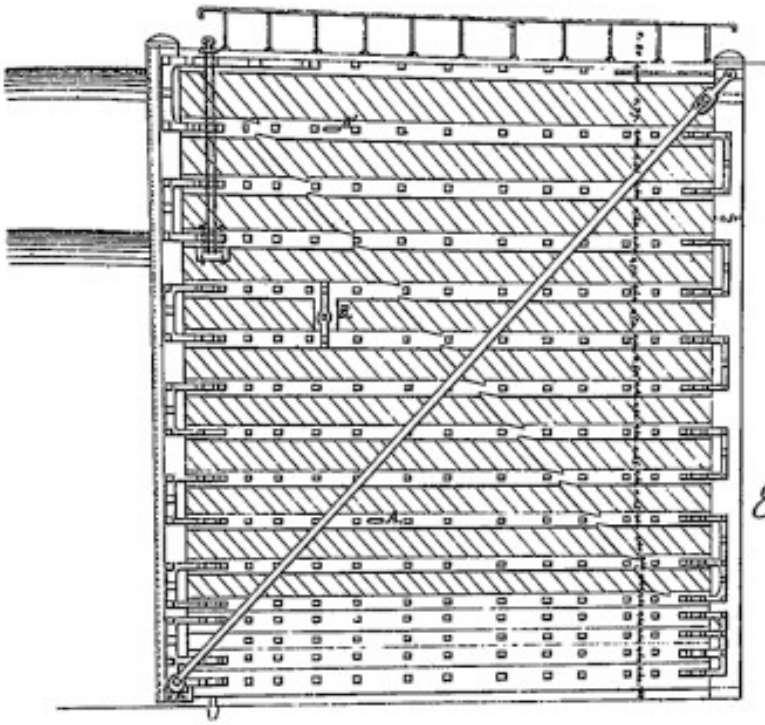
Pl. 5.e

Dispositions Générales d'un Grand Port de l'Océan.



Pl. 6.

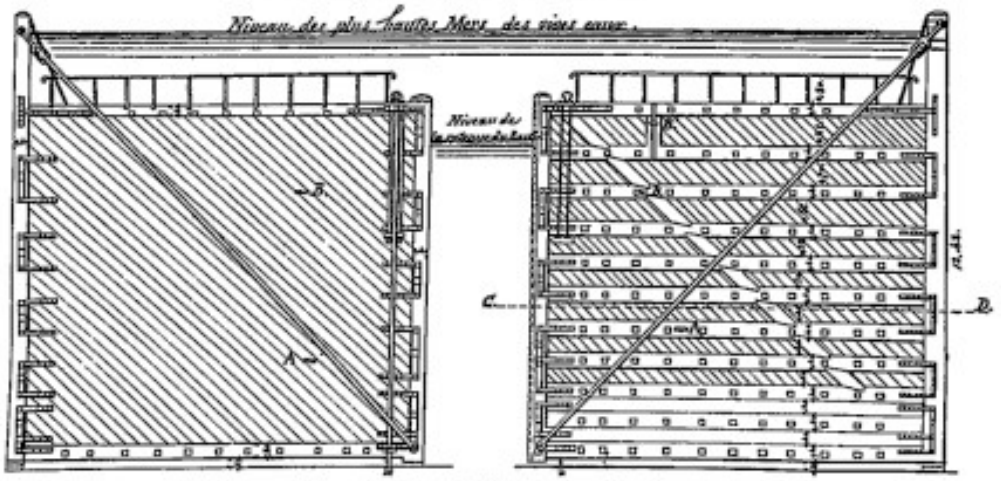
Ventail des Portes de flot.



Les points d'attache des Chaines d'ouverture sont A. et B.
Les points d'attache des chaines de fermeture sont A' et B'.

Portes du Bassin à flot
Entre S.t Servan et S.t Malo.

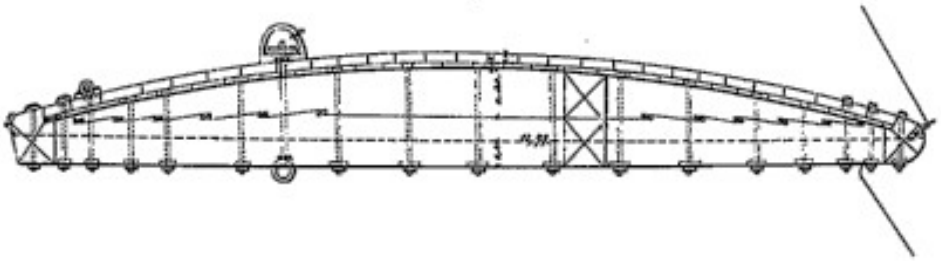
Ventail des Portes d'Ebe.

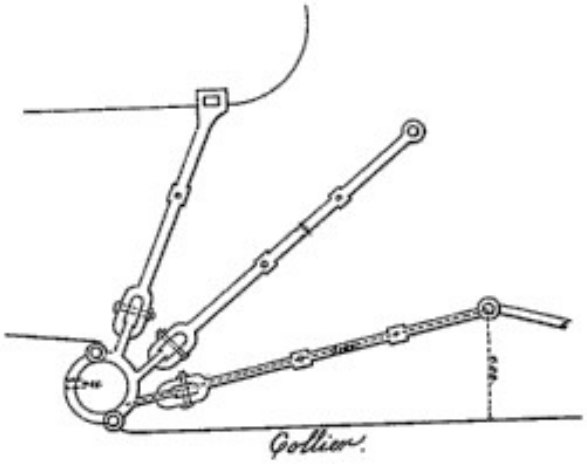


Note. A est le point d'attache des chaines d'ouverture et de fermeture inférieures.
B. est le point d'attache de la chaine d'ouverture supérieure
B' celui de la chaine de fermeture supérieure.

Pl. 7.

Coupe sur la ligne C D.



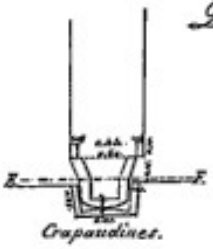


Collier.

Coupe du Collier.

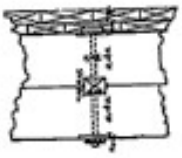
Collier

Coupe sur G H.



Crapaudinet.

Détail d'un Boulon.

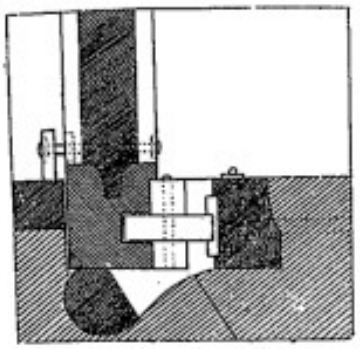


Coupe sur E F.

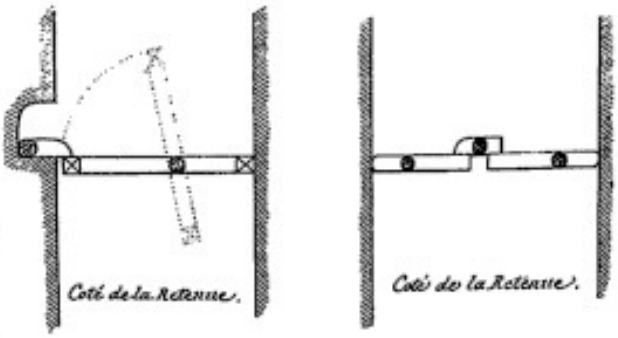
Plan Supérieur.

Pl. 8.

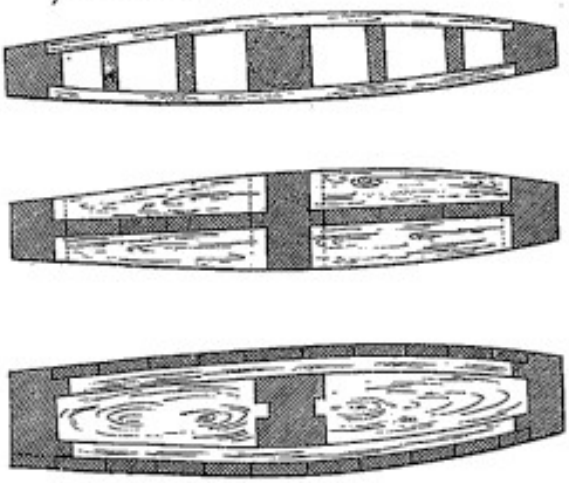
Vanne à roulettes pour les Ecluses de chasse.



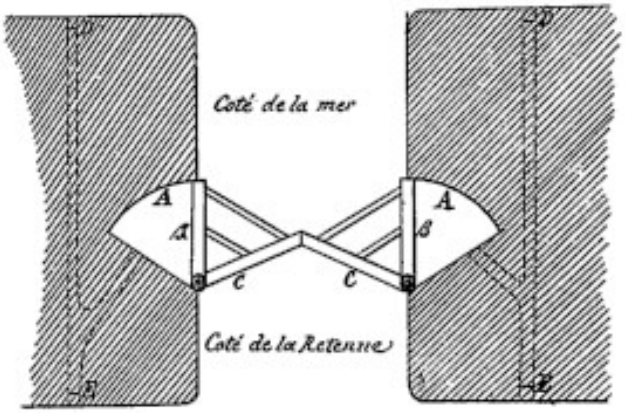
Portes tournantes



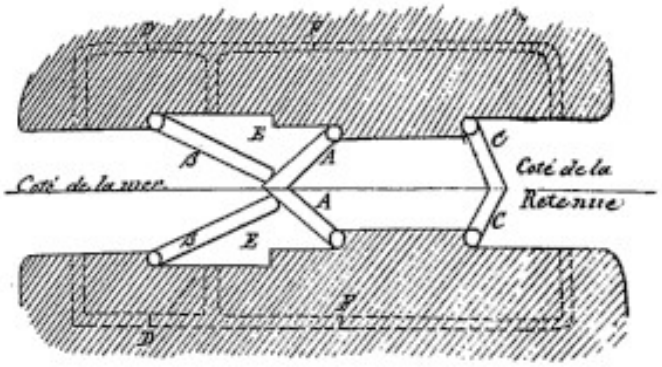
Trois systèmes de portes tournantes pour Ecluses de chasse.

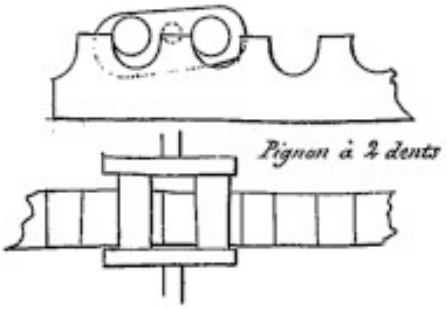


Mode de fermeture exécuté à une ecluse en Hollande.



Ecluse de Gouda en Hollande.





Glossary of Some Maritime Construction Terms

Source Abbreviations:

AF: Dictionnaire de l'Académie Française *(Dictionary of the French Academy)*

DM: Dictionnaire universel de la marine – Ch. de Bussy – 1862 *(Universal Dictionary of the Navy)*

E-Univ.: Encyclopédie universelle (*Universal encyclopedia)*

CDM: Lexique du "Canal du midi" *(Glossary of the "Canal du midi")* (https://www.canaldumidi.com/Geographie/DicoTech.php)

Littré: Dictionnaire de la langue française de E. *Littré* – 1874 *(Dictionary of the French language)*

CdTM (1 or 2): Cours de travaux maritimes - École Nationale des ponts et chaussé - Baron Quinette de Rochemon - 1900 (T. 1) / 1901 (T. 2) *(Maritime works course - National School of Bridges and roads)*

ФРУС: Французско-русский универсальный словарь *(French-Russian Universal Dictionary)*

БФРС: Большой французско-русский и русско-французский словарь *(Large French-Russian and Russian-French Dictionary)*

ТСС: Терминологический словарь по строительству на 12 языках *(Terminological Dictionary of Construction in 12 Languages - All-Russian Scientific Research Organization)* (ВНИИИС Госстроя СССР – 1986)

Мс: Морской словарь в 2 томах государственное военно-морское издательство нквмф союза ССР москва 1941 ленинград *(Naval Dictionary in 2 volumes, State Naval Publishing House of the People's Commissariat of the Navy of the USSR, Moscow 1941, Leningrad)*

Др: Other...

Anguilles

DM(*) – (Ways; bilge ways.) Long, strong pieces of wood that serve as the base for a ship's cradle. Those that carry the ship to sea are called *coittes courantes* (moving ways); those that only keep it in a given direction are called *coittes mortes* (stationary ways).

Mc – steep, high river bank; quay.

Arquer

DM – (To become broken-backed, or cambered.) To curve into an arch; to take on an arch (see this word). A ship is *arqué* or appears so when its ends are or seem to be lowered relative to its middle. — A ship becomes arqué as soon as it is launched, because the surrounding water does not support it in all its parts according to their

(*) All English terms in parentheses in the dictionary are those of the original editions

particular weight, or because the water displacement is not in this ratio between its ends and its middle part. — At sea, a ship beaten by waves, stressed by its rigging, takes on a new curve; its greatest deflection or the most noticeable alteration of its original contours usually corresponds to the region of the *dogue d'amure*. — A arquée keel (cambered heel) is one that is no longer straight; an *arqué* deck (cambered deck) is one that has lost its initial sheer; an *arqué* ship (broken-backed ship) is one whose longitudinal curvature is no longer regular and uniform.

Atterrissement (sédimentation)

AF – Derived from the root of the present participle of *s'atterrir* in the old sense of "to fill (itself) with earth". Deposit formed by alluvium. Atterrissements always form in the concave part of a meander.

ФРУС – accumulation of alluvium, alluvial deposit, alluvial land, deposition of alluvium, silting, process of alluvium accumulation, process of formation of alluvial deposits by a river.

БФРС – sediment formation (geol. formation of sedimentary rocks).

Avant-port

DM – (Outer port.) Sea area preceding a port; it can provide shelter for vessels.

AF – 1. Advanced part of a port facility, providing access to the various basins of the port proper and the inner harbor.

TCC – Outer part of a port, protected from waves by natural shelters or protective structures and adapted for anchoring, loading and unloading ships.

Avant-Cale

DM – (Launch.) Seaward extension of the floor or slipway on which a vessel is built while under construction. It serves as a bridge for a vessel to go from its building slipway to the sea.

Mc – Launching foundation, part of the slipway device which receives, via the sliding ways, the weight of the ship to be launched. A distinction is made between the launching foundation above water and that below water. The above-water foundation is the above-water part of the slipway on which the launching ways are laid out; these ways are intended for the movement of the launching sliding ways, or cradle, on which the ship is placed before launching. The underwater foundation serves to establish launching ways underwater which are the continuation of the ways installed on the above-water foundation. The installation of such underwater ways is necessary so that the launched ship can already float before leaving the underwater foundation. The launching foundation, like the slipway, has a certain slope, varying according to the size of the ship; to allow this slope to be modified, a temporary wooden foundation is built over the permanent foundation.

Bajoyer

AF – 18th century. Derived from *joue* (cheek), by blending *jouyer* and *bajoue*. Public works. Masonry revetment along an embankment, watercourse, canal, and especially a lock. The width of a lock between two *bajoyers*.

CDM – The masonry walls of the lock chamber, parallel or slightly oval, also called quay walls.

ФРУС – 1) dry dock wall, abutment (on a river), side wall of a lock chamber, retaining wall. 2) retaining wall, wall (e.g., of a lock).

Bassin

DM – 1. Sheltered place, in certain ports, where vessels are safe from wind and heavy seas (small harbour). 2° Stone enclosure found in military shipyards into which sea water is introduced (dock, or basin of a dock) through gates large enough to allow passage of vessels placed there for repairs (see *forme*).

Littré – Part of a port where vessels are afloat and sheltered from the agitation of the sea.

Mc – Enclosed body of water. For navigation purposes, special basins are laid out in ports and roadsteads for fitting out, handling, and repairing ships. In ports with large tides, special tidal basins are laid out (Tidal basin). These basins are separated from the sea either by special gates or by lock chambers; the water level is always maintained at the height of mean tide. With gates, the basin can only be opened for the time (1 to 2 hours) when the sea level is higher than the constant level of the basin; with locks, the basin operates continuously.

Bassin à flot

AF – Enclosure communicating with the sea and closed by a lock so that the water level remains constant and is not subject to the movement of the tide.

E-Univ. – Basin connected to the outer harbor by a lock and in which the water level is maintained close to that of high tide.

Mc – Floating dock — floating structure intended for lifting ships and consisting of a pontoon, on the sides of which rise side walls (towers), solidly connected to the pontoon. The floating dock is divided by watertight bulkheads into compartments which, when the dock is submerged, fill with water by gravity through special valves operated by rods from the upper deck of the walls. When the dock is raised, water is pumped out by pumps located in the lower part of the pontoon and driven by electric motors or steam engines placed on the upper deck of the walls. Self-elevating floating dock — floating dock composed of several pontoons connected on each side by common continuous walls. The pontoons of the dock can be separated from the towers for repair and painting and be raised in turn by the dock itself, supported by the other pontoons.

Bassin de chasse (retenue)

See *Chasse*

Bassin de retenue

Littré – Space between two locks, where water is retained.

Bassins de radoub

DM – 2° Stone enclosure found in military shipyards into which sea water is introduced (dock, or basin of a dock) through gates large enough to allow passage of vessels placed there for repairs (see *forme*).

AF – Watertight pit that can be drained to carry out maintenance and repair of ships. Careening dock, building dock.

Mc – Dry dock — dock built on shore in the ground, whose bottom lies below the level of the lowest water so that the corresponding ship can be floated in. The bottom, side walls, and rear wall of the dock are lined with stone and concrete blocks, while the front wall is replaced by a movable closure device at the dock entrance. The closure devices are of two systems: either sliding gates, or a floating closure device — a caisson (gate-caisson or *bateau-porte*). In the middle of the dock, along its bottom, a protruding track is laid out to receive the keel blocks. Near the dry dock, a special room is laid out for pumps used to evacuate water from the dock.

Bateau-porte

DM – *Bateaux-portes* close the opening of basins in ports.

CdTM 2 – A bateau-porte is a removable watertight screen, capable of floating to clear the passage it closes, and which can be sunk in place by the introduction of water ballast; the lower and lateral surfaces then bear on a sill and on two rabbets located in the same plane. The bateau-porte is brought into the lock and beached before the dock is drained; it is raised after filling, the water ballast used to sink it having been previously removed.

Mc – (Ponton dock-gate) — closure installed at the entrance (gate) of a dry dock to isolate the interior part of the latter from sea or river water. The caisson is a steel watertight box, having an internal platform and divided into compartments.

Ber or berceau

DM – (Cradle.) A kind of bed made of ropes and strong framing pieces, on which a vessel is rested, when, after having been built on shore on an inclined building site, it is intended to be launched. The cradle embraces a large part of the hull; it slides towards the sea, as soon as it is freed from everything that might hold it back, carrying with it the vessel which abandons it when it succeeds in finding a new support in the water. A cradle has as its base two *coittes*, on which are erected uprights called *colombiers*, held by ropes passing under the ship's keel. Those in the middle support their notched heads under a strong, long piece of wood called a *ventrière*, which serves as a half-belt for the broadest contours of the lower part of the hull.

БФРС – maritime: launching cradle.

Béton en sacs

CdTM 1: "Bag concrete is preferable to concrete poured directly under water; washing away is less to be feared, and the often considerable weight of the mass falling at once means that the bags mold themselves to the ground or to each other. Their use is well justified in some special cases, notably for leveling the roughness of rocky ground or the top of riprap, for providing foundations for relatively unimportant structures, or for forming protective enclosures. It has sometimes been used in France under specific conditions, but care has been taken not to generalize its use to the point of making it one of the constituent elements of important works. Since the bags are not filled so that they mold onto each other, it often happens, when they are large, that the concrete shifts and moves towards the ends; these, consequently, sometimes tear and leave the concrete exposed. Compactness is also not assured; the welding together of bags immersed at different times is not certain, given, in particular, the difficulty of cleaning the surface of the bags laid earliest."

Mémoire sur les travaux à la mer (Thesis on the work at the sea) – L. V. Poirel – 1841:
"This method of manufacturing artificial blocks was arrived at by a process used by the Italians, when they want to repair scour holes occurring in masonry under water. This process consists of filling bags similar to the sandbags used in fortification with concrete, to be placed on top of each other in the opening to be closed. Based on this idea, they filled a bag much larger than the sandbags with concrete and threw it into the sea during a storm; and after a few days, when the sea was calm, they found this block very hard and very resistant."
[*caisses-sac - bag boxes (ibid)*] "The walls of these boxes are formed by a lattice of beams, covered internally with a double course of planks with crossed joints forming a shell. The lower part is cut out approximately according to the profile of the ground on which they are to rest. They are lined inside with tarred canvas, fixed around their entire perimeter and forming a bag. This canvas, nailed to the framework, extends over the total height of the box up to above the water level. The four panels of the box are assembled by hinged iron brackets, so that they can be easily dismantled. They are removed after ten to twelve days; and to use them again, it suffices, either by cutting them or lengthening them, to shape them roughly according to the shape of the ground. Once assembled, a canvas is fitted to them which must have sufficient fullness to conform to all the sinuosities of the bottom it covers. The box thus forms a real bag, whose sides are reinforced by wooden panels over which the canvas is stretched and fixed. The mass of concrete filling it can therefore mold itself perfectly to the ground and bond with it through the very roughness it presents; whereas with flat-bottomed boxes generally used for founding underwater structures without dewatering, one must strive to eliminate ground irregularities by leveling it to an approximately even surface, a difficult operation that can never be more than imperfectly successful."

Bigues

DM – (Sheers.) 1° Long, strong fir pieces which, in a masting machine, support the tackle used to raise a mast. 2° Tall uprights erected around a ship under construction, carrying pulleys at their heads which facilitate the raising and arrangement of the large component pieces of the vessel. 3° Strong pieces of wood serving as levers to incline a small vessel onto one of its sides. 4° Two pieces of wood joined at one of their ends to form a kind of sheer legs, with which heavy loads are lifted and loading or unloading of a vessel is facilitated.

БФРС – lifting, assembly tripod; jib crane; (lifting) crane, (cargo) boom.

Bordages

DM – (Plank.) Name given to planks of varying thickness used either to cover the entire outer surface of a ship's hull, or to form the decks or floors distributed inside vessels. Some have particular names, such as *préceintes*, *carreau*, *ribord*, *lisses de rabattue*, *hiloires*, *bordages de fonds* (plank of the floor), *bordages des gaillards et de la dunette*, etc. — The word *bordage* sometimes expresses the action of planking a ship or applying planks in their place.

БФРС – planking board.

Bracon

E-Univ. – Reinforcement piece, arranged diagonally between the foot of the hinge post and the top of the miter post of a lock gate.

ФРУС – 2) construction: diagonal tie, strut.

Brise-lames

AF – 19th century. Composed of *brise*, verb form of *briser* (to break), and *lames* (waves). Structure built at the entrance of a port or roadstead to protect them from waves coming from the open sea.

TCC – Breakwater — Hydraulic structure to protect the water area of roadstead berths, approaches to channels and locks, and coastal areas of the sea from waves.

Busc

AF – In a lock, a projection on the sill against which the lower part of the gates abuts.

Busqué (Porte, Poteau)

AF – Having a convex curvature.

Cadranure

E-Univ. – Wood defect characterized by cracks arranged like the hour lines of a dial (Forest. 1946). No more than cadranure can roulure be detected in the standing tree (*J. Cochet, Culture, aménagement et amélioration des bois*, 1963, p. 27).

Mc – star shake — cracks in standing trees, radiating from the pith and following the axis of the trunk; the harm of this defect depends on the size and direction of the cracks.

Cale

DM – 2° Building slip (building slip), extensive, inclined, artificial base on which a vessel rests during its construction; placed under a high roof, it is called a covered slipway; used as a base for vessels undergoing any repairs, it is called a careening slipway or repair slipway.

Cale de halage

AF – Repair device consisting of an inclined plane fitted with rails on which rolls a cradle, or *ber*, which supports the ship to be repaired.
See also *Avant-cale – Mc*

Chardonnets

Littré – 2° Term of bridge and road construction. Refers to the stones of locks bearing the rabbet in which the hinge posts turn.
E-Univ. – Vertical member of a carriage gate leaf which carries the ironwork by means of which pivoting occurs. Vertical part of the masonry of a lock head, against which the hinge post of a miter gate leaf rests when the latter is closed.

Chasse

AF – Artificial current created in a port to clear a channel of sands brought in by the tide. A *bassin de chasse* (flushing basin).
Littré – Flushing reservoir, a vast space closed by a lock, which is opened to the rising sea at high tides, and closed as soon as the sea begins to fall, to be reopened suddenly when it is completely low; the water, then rushing with great violence, flushes away the shingle or sands obstructing the entrance to ports.

Chenal (Canal)

DM – 1° Space in which the sea is constricted, between two continents, between two islands, or between an island and a continent: such as the English Channel, the Mozambique Channel, etc. A vessel entering a channel is said to *faire canal* or *donner dans le canal*. — 2° Similar space placed in a sea obstructed by reefs and offering vessels a safe and easy passage. In this case, *chenal* is also used.
AF – 1. Narrow passage, natural or artificial, allowing navigation between rocks, shoals, islands, or connecting a port to the open sea. Navigation channels. The port's entrance channel was marked by buoys.
Mc – (Maritime) canal — artificially created waterway according to predetermined underwater and surface dimensions, with a provided normal method of vessel movement; artificially deepened channel leading to the port through the coastal bar.

Coëttes (Coittes or Anguilles)

Misspelled, as the Dictionnaire universel de la marine uses the spelling *Coitte* (with a typo in the index, *Coite*). This may be due to an attempt at phonetic transcription of the Breton pronunciation of "oi", [ɔj] which would give [kɔjt] or [kwait].

See *Anguilles*

Colliers

AF – Circular band, most often metallic, used to fix a tube, a pipe, a cable, etc.

Contrefiche

AF – Piece arranged obliquely to prop up a wall, panel, or any other vertical element.

Др – Single-strut system — wooden bridge system in which the middle of each longitudinal beam or crossbeam is supported by two struts mortised into each other. *Термины российского архитектурного наследия (Terms of the Russian architectural heritage). Плужников В.И., 1995*

Crapaudines

AF – Vertical bearing serving as an abutment and ensuring the guidance of a rotating part.

БФРС – tech.: pivot bearing; thrust bearing; pivot, eye; stop (of a hinge).

Mc – Pivot bearing — (Foot step bearing) support part supporting a vertical shaft and receiving all the load acting along the shaft axis.

Déraser

AF – To level ground by lowering its level; to partially demolish a structure to bring it to the desired level.

Digue

AF – Structure which protects a port from the open sea swell. A lighthouse occupies the end of the digue.

Mc – Dam, sea-wall, dike — hydraulic structure in the form of an embankment serving to protect an area from flooding, to carry a road platform, or to regulate river flow.

Ebbe

DM – Synonym of *Jusant* (see this word).

AF – (Ébe) Maritime term, used in several provinces for the ebb of the sea.

БФРС – falling tide (in Normandy).

Écharpes (Lisses)

DM – lisses de l'éperon or *Écharpes*, or *Porte-vergues*, or *Herpes* (rails of the head), long curved pieces of wood, three on each side of the stem, extending from the *éperon* (cutwater) to various points of the ship's cheek, diverging from each other, and embracing the *poulaine* (head rails).

AF – Rope that is tied around a heavy load in order to move it.

Joinery – Piece of wood or iron, fixed diagonally, which serves to hold together the vertical planks of a panel. A diagonal brace.

Échouage

DM – Situation of a vessel which, not being surrounded by a sufficient depth of water to keep it afloat, necessarily rests on the seabed.

E-Univ. – Situation of a ship which intentionally touches the bottom and ceases to float. *Échouage au bassin* (dry-docking). *Échouage d'une barque sur la plage* (beaching of a boat). *Port d'échouage* (tidal port). Contact with the bottom by a stationary vessel due to a lowering of the water level. Place where a boat, a craft can be beached without danger.

Enrochement

AF – Heap of rocks thrown into a seabed, river, or shifting ground to serve as a foundation and prevent scour.

БФРС – stone bed; rubble filling; riprap.

ФРУС – stone fill.

Épaufrure

AF – Chip accidentally detached from a dressed stone, a marble block, a sculpture.

ФРУС – stone chipping.

Étale

DM – The sea is *étale* (high water; slack water), when it is in a stationary state, i.e., when the daily flood or ebb is finished.

Др – turn of the tide (zero current) — *Русско-французский географический словарь (Russian-French geographical dictionary)*.

Forme

DM – (Wet dock.) Space which, in the same basin, can receive several vessels.

AF – Beaching basin where boats are repaired. *Faire passer un navire en forme* (to put a ship into dock). *Forme de radoub* (repair dock) (also called *Bassin de radoub* or *Cale sèche*).

Mc – Wet dock — basin or series of communicating basins for vessel parking. At the entrance of the wet dock are gates or a floating caisson, connecting the basin to the sea or river during high water (tide) and closed during the ebb; thus, the water level in the wet dock is always kept constant, which offers considerable advantages, allowing deep-draft ocean-going vessels to access relatively shallow ports subject to tides. Wet docks are particularly widespread in England and the Netherlands.

Mc – Dock — special structure intended to receive ships for repair, inspection, or painting of their underwater part, as well as for parking in tidal ports. The dimensions of the dock depend on the dimensions of the ships for which it is intended. To dock a ship (To dock a ship). To enter the dock (To enter the dock). To come out of dock (To come out of dock).

Fourrures

DM – 3° pieces of wood (furrings) that carpenters apply to wooden pieces to reinforce them (*fourrure d'une vergue* - yard packing), or to repair defects they have in their contours;

БФРС – 5) maritime: packing, furring.

Gabare

DM – 2° flat, undecked boat (barge) which, on rivers or seacoasts, serves for transporting goods from one ship to another or from a ship to port. The masters of these boats are called *Gabariers* or *maîtres de gabares*; they sometimes engage in short-sea shipping.

Gélivure

AF – Crack or split in a trunk or branch, caused by frost.

Др – crack appearing along the fibers, often over the entire length of the trunk, during severe frosts. In spring, these cracks close and heal, but often reappear in winter. If this repeats several times, ridges form on the tree, in which rot can appear over time. *Технический железнодорожный словарь (Railway Technical Dictionary)*. 1941.

Guideau

E-Univ. – Dam made of inclined planks, to direct water flow. *Dresser des guideaux à l'entrée d'un port* (to set up guide piles at the entrance of a port).

ФРУС – guide pile.

Jetée

AF – Structure made of wood, stone, or other materials, built along the channel of a port or in a watercourse to break waves and direct currents.

Mc – Mole (Mole, jetty, dam) — protective structure protecting the port area from wave action. Can also serve for the installation of berths, handling equipment, and other devices. A signal light or lighthouse is installed at the seaward end of the mole.

Jusant

DM – (Ebb or ebb tide.) Daily movement of the sea, which physicists call reflux. If, during the flood (flood), the sea brings new waters to the shores and rises to a greater or lesser height above its natural level, conversely, during the ebb, it runs in the opposite direction. — When this movement of the sea is established, it is said there is *jusant* (the tide ebbs or falls); if it is lively and rapid, there is *grand* or *fort jusant* (main ebb); when this movement dies down, the *jusant* is *étale* or *est étalé* (slack water).

Lame

DM – Wave, roller, or more or less high mountain of water, which the wind produces, increases, and maintains on a sea whose surface it agitates. — A *grosse lame* (high sea) is high and wide at its base; a *lame longue* (long sea) has a base embracing a long space; a *lame courte*, a *mer courte* (short sea) refers to several low waves covering a

small space. Waves that break (to unfurl) are those that strike each other. — A vessel which, being between two high waves, cannot receive the wind in its sails, is sheltered by the wave (becalmed in the trough of the sea). — A vessel *a la lame par le travers* (the sea strikes upon her broad-side), when it is directed against one or other of its flanks; it *fuit la lame* when it runs before the wind (to run away).

Mailletage

DM – 1° Action of *mailleter* a ship. 2° Product of this operation.

Mailleter

DM – (To sheath a ship's bottom with nails.) To cover the outer surface of a ship's hull with nails. These nails are distributed so that their heads, 6 to 8 lines wide (approx. 13.5 to 18 mm), are only 5 to 6 lines (approx. 11 to 13.5 mm) apart, and the rust that follows soon fills this interval, so that shipworms can no longer then sting and pierce the wall of a ship thus prepared.

Môle

AF – Masonry massif which protects the entrance to a port by obstructing waves coming from the open sea, or which divides a basin into docks to allow ships to berth.
See also *Jetée*.

Mortes eaux

DM – *Le mort de l'eau* or *le mort d'eau* (neap tide), or *eaux mortes*, indicate the time when tides are less considerable during a lunar month, i.e., the time of the moon's quadratures.
ФРУС – neap tide.

Musoir

AF – Inclined end of a jetty, a breakwater.
БФРС – pier head; mole point; end of a dam; lock head corner.

Port d'échouage

AF – Beaching place or, by metonymy, archaic, *échouage*, a place on a coast where a small boat can be beached without danger, such as a smooth beach, a sandy bottom.

Poteau busqué

CDM – Post of a lock gate leaf which abuts against that of the other leaf when closed.
ФРУС – miter post.

Poteau tourillon

CDM – Post forming the axis on which a lock gate leaf pivots.
ФРУС – hinge post.

Poulier

AF – Curved point of a coastal spit, which tends to block the entrance to an estuary.
ФРУС – shingle and sand bank, gravel and pebble shoal.

Quai

DM – (Quay.) Space along the sea or a river; it is often an embankment faced with stone, but always prepared in such a way as to facilitate both the approach of vessels, and their loading and unloading. A vessel is *à quai* when it is alongside a quay.

AF – Earth embankment, most often covered with a masonry facing, built along a coast or watercourse to prevent overflowing, retain shore land, and allow ships to berth.

Quadrature (marée de)

Mc – the smallest tide, when the Sun and Moon culminate one after the other after 6 hours, i.e., when they are in quadrature, and the tide-generating forces of the moon and sun act at right angles to each other and their total force is the smallest.

TCC – Neap tide — the weakest tide, when the Sun and Moon culminate one after the other with a 6-hour interval, i.e., at the first and last quarter of the Moon (quadratures). The weakest tide, when the Sun and Moon culminate one after the other with a 6-hour interval, i.e., when they are in quadrature, and the tide-generating forces of the Moon and Sun act at right angles to each other, their total force then being the weakest.

Rade

DM – (Road.) Expanse of shallow sea partly enclosed by more or less high land, and offering vessels anchorages sheltered from wind and waves.

Mc – Roadstead (Roadstead, road) — more or less extensive body of water in the vicinity of the shore, constituting a suitable anchorage for ships, protected from wind and wave action. Depending on the degree of protection against wind and waves, roadsteads are divided into open roadsteads and closed roadsteads. The latter, in the absence of natural shelter (a projecting cape, coastal island, or shoal), are created by means of protective structures: moles and breakwaters. The roadstead must have a depth not exceeding 40 m, with a suitable bottom capable of holding the anchor well (e.g., mud), and present no underwater dangers. A great advantage of the roadstead is its access from the sea, which is sufficiently wide and free from dangers, as well as the absence of obstacles to entering the roadstead in any weather, at any time, including at night. A roadstead having several entrances is preferable to a roadstead with a single entrance, mainly from a military point of view, not to mention the convenience of entering and leaving in different winds. Sometimes, cargo transfer operations between ships or ship bunkering are carried out afloat in the roadstead.

Rades foraines

DM – (open roads), roadsteads which are only partly enclosed by high land, and are openly exposed to several sea winds when they prevail.

Mc – (Outer harbour) — roadstead located outside the protected part of the port.

Radier

AF – Timber or masonry platform serving as a foundation for a structure exposed to water action or built on loose soil.

TCC – Apron — the assembly of parts of a spillway dam over which an open water flow passes, including the upstream apron, the spillway crest, the stilling basin, and the downstream apron.

Radoub

DM – (Repair.) More or less extensive repair made to a seagoing vessel.

AF – Maintenance and repair of a vessel's hull.

БФРС – repair of the underwater part of the ship; repair of masts; repair of sails.

Mc – Ship repair (Repair, repairing) — aims to restore worn or damaged parts of the hull, rigging, equipment, and machinery; this should also include the replacement of ship devices and machinery of obsolete types with more recent, technically more advanced samples (modernization). According to the size and nature of the work, ship repair is divided into: preventive, routine, major, and emergency repair.

Reflux

DM – See *Jusant*.

Roulure

AF – Wood defect presenting a circular crack between two adjacent rings of the trunk.

Mc – Ring shake — crack along the annual ring, sometimes affecting only part of the ring, sometimes the complete ring.

Syzygie

Littré – 1° Astronomical term. Positions of the sun and moon when these stars are in conjunction or opposition, i.e., at new and full moon.

Mc – Syzygy — position of the Moon when its longitude is either equal to the longitude of the Sun (conjunction), or differs from the latter by 180° (opposition); in the first case, new moon occurs, and in the second, full moon.

Tarets (vers)

AF – Small marine bivalve mollusk resembling a long worm which bores galleries in submerged wood.

Tourillon

AF – *Tourillon* - Cylindrical part serving as a rotation axis.

Littré – Cylinder movable in a bearing, by means of which any apparatus can receive a rotational movement; tourillons are always coupled in pairs, and they have the same axis which is horizontal.

Др – Journal, gudgeon, pivot — 1. Tenon, part of a shaft or axle which rests on a bearing and rotates in it. *Толковый словарь Ушакова (Ushakov's Explanatory Dictionary). Д.Н. Ушаков. 1935-1940*

Triqueballe

AF – Towed device used for transporting long and heavy loads, notably logs, consisting of a crossbar mounted on large-diameter wheels, under which the load is fixed.

БФРС – 1) cart for transporting logs, timber bogie, logcart.

Valet (de porte)

Littré – Counterweight which, hanging behind a door, makes it close without being touched. Iron bar serving as support for the door leaf.

Ventelles(*)

AF – *Vantelles* or *vanelles*: Small valve located on a lock gate.

Littré – *ventelle*: Opening made in the *ventellerie*.

Ventellerie: Term of bridge and road construction. Wood or masonry structure, intended to support a water head: one or more openings are made in it which are closed with valves.

Course on the construction of works establishing navigation on rivers and canals, taught at the École des ponts et chaussées from 1832 to 1841, by Mr. Minard: "The ventelles of gates are usually placed between the last two lower crosspieces; their distance from the posts depends on the best position they can have relative to the diagonal brace and the strut which obstruct their opening and hinder their mechanism. For this reason, their width varies from 0.60 m to 0.40 m; their height is the interval between the crosspieces. When they are in the angle of the miter post, the fluid jets from the two leaves collide immediately at their exit from the orifice, and the flow is somewhat impeded.

The ventelles are usually composed of small horizontal planks (fig. 318), assembled with tongues and grooves, and held by hinges and horseshoe-shaped iron fittings m m (fig. 306), ending in a rod pp used for operation. The planks slide in runners formed by two pieces of wood applied against small posts; these runners, projecting 0.12 m to 0.15 m from the plane of the gates, force the groove to be made deeper or recesses to be made in it. Iron runners are therefore often preferred, and sometimes even the ventelles are placed within the thickness of the gates to avoid any projection. Sometimes the ventelles are made of cast iron or sheet metal fixed on a wrought iron frame.

To operate the ventelles, iron or cast iron jacks are generally used."

Vireveau (or virevau)

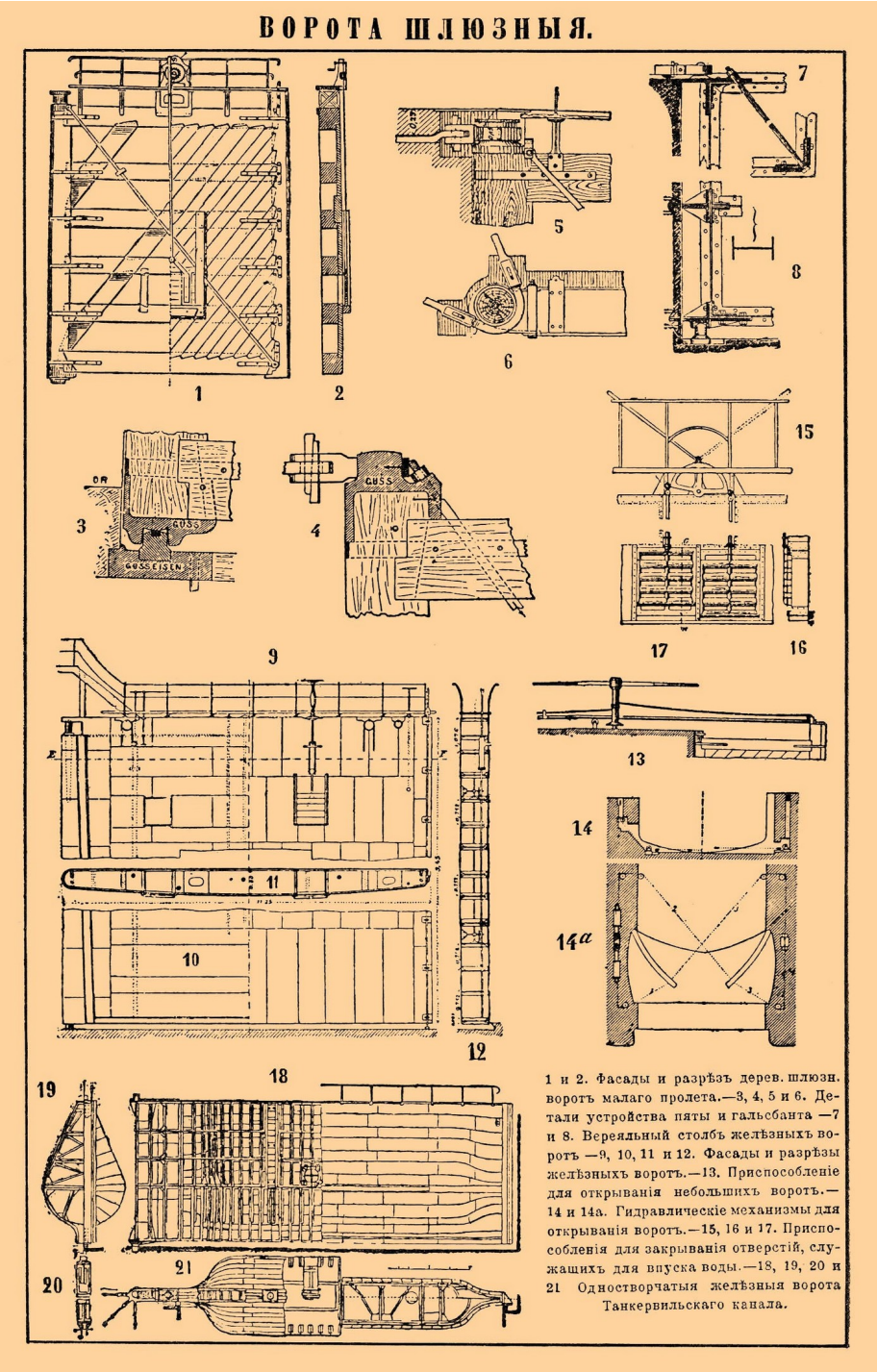
Littré – Maritime term. Horizontal capstan turning on two pivots, serving, on certain ships, to raise anchors and all heavy loads.

Vives eaux

DM – *Eaux vives* (spring tides) is the name for tides occurring at the time of syzygies.

БФРС – spring tide.

(*) The dictionary of the French Academy spells it with an a but all the courses taught at the École des Ponts et Chaussés, published, use the spelling "Ventelle", as Littré.



Lock Gates

1 and 2. Elevations and cross-sections of wooden lock gates for small spans.

3, 4, 5 and 6. Details of the pivoting (or bearing) device and the fixing strap.

7 and 8. Assembly post for iron gates.

9, 10, 11 and 12. Elevations and cross-sections of iron gates.

13. Opening device for small gates.

14 and 14a. Hydraulic mechanisms for gate opening.

15, 16 and 17. Closing devices for water inlet orifices.

18, 19, 20 and 21. Single-leaf iron gates of the Tancarville Canal.

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